GENERAL ELECTRIC REVIEW

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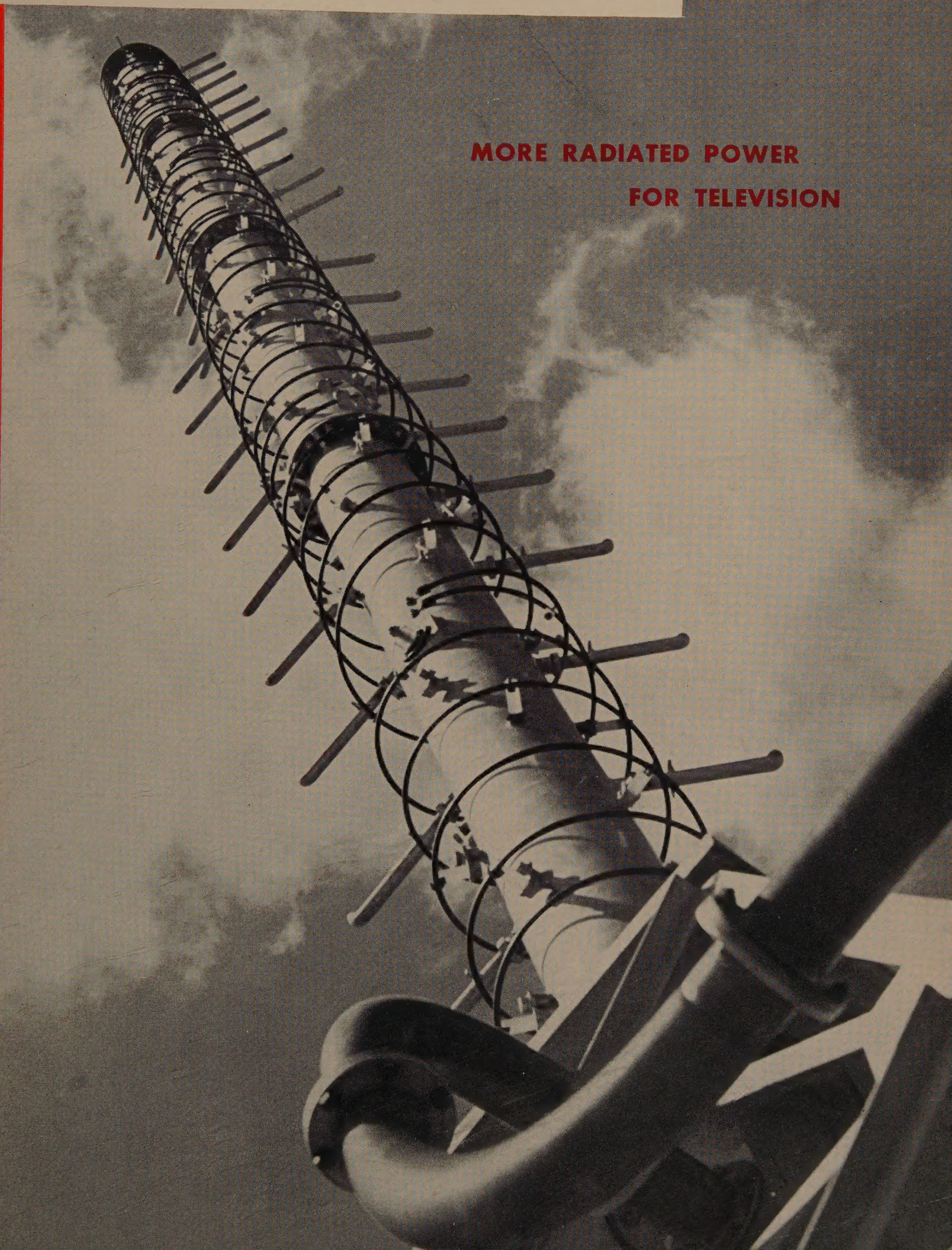

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FOR TELEVISION

t

. 8

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- ✓ Continuous expansion to meet customers' requirements has made American Lava the world's largest producer of custom made technical ceramics exclusively.
- ✓ Average daily production approximates four million parts and is rapidly increasing.
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ALSIMAG

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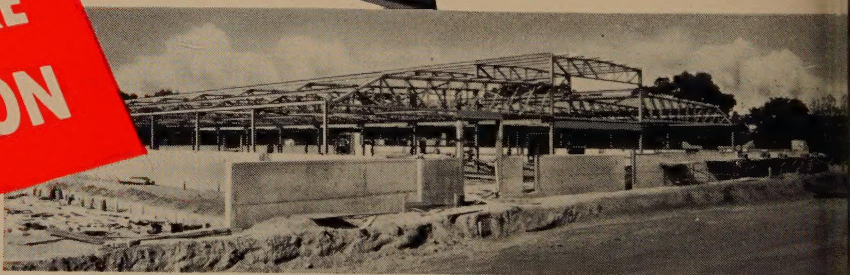

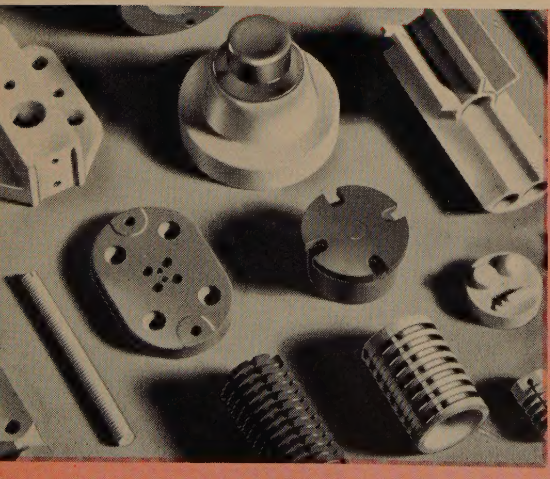

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GENERAL ELECTRIC Review

AUGUST, 1951
Vol. 54, No. 8

EVERETT S. LEE
Editor

R. E. MAY
Circulation and
Advertising Manager

J. E. GLICK
Associate Editor

THE COVER

40-foot helical antenna is now being used by
Electric engineers conducting UHF tele-
ests at Electronics Park, Syracuse, to boost
radiated power of their transmitters by 20
The structure is made up of four sections,
ving a right-hand and a left-hand helix, with
the center, from which helical antennas can
to operate on any channel in the UHF band.
tenna is being used with the world's most
l UHF transmitter, currently rated 5 kilo-
out to be boosted to 12 kilowatts soon.

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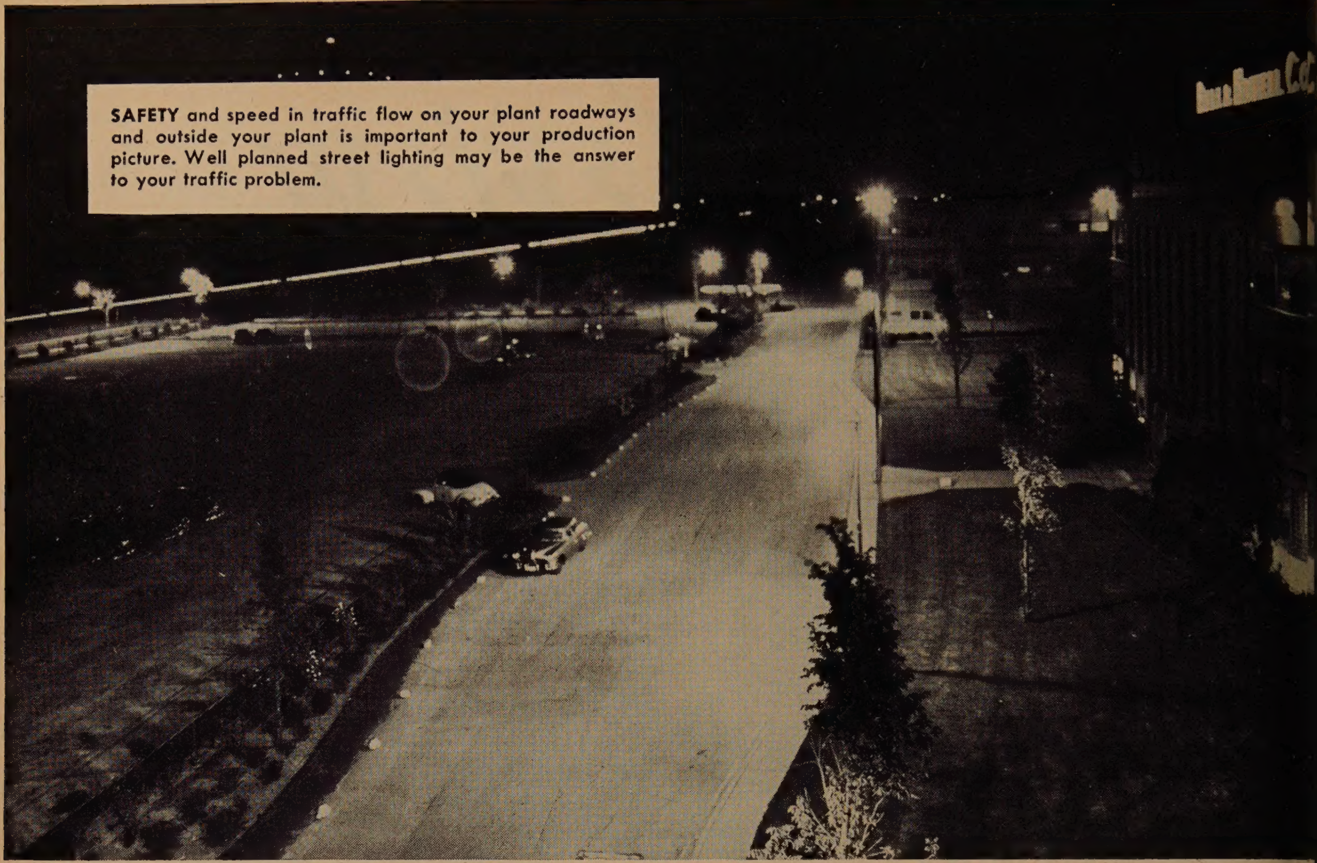


SAFETY and speed in traffic flow on your plant roadways and outside your plant is important to your production picture. Well planned street lighting may be the answer to your traffic problem.

Can you afford to neglect Lighting on your outdoor production lines?

As production becomes the key word in today's industrial picture, you are again faced with the problem of "keeping 'em rolling" from entrance gate to railroad siding.

Plan now to keep the out-of-doors elements of your plant at peak operation with soundly planned outdoor lighting. New types of fixtures, improved lighting techniques, minor adjustment of your present lighting equipment can give you a completely modern system at moderate cost.

For planning help call in the lighting specialist at your local G-E office. He is trained in today's lighting requirements and techniques. Or write for the free bulletin *Outdoor Lighting for Industrial Plants. (GEA-3640.) Apparatus Department, General Electric Company, Schenectady 5, N. Y.*

SPEED is becoming the vital factor in production and distribution. For a modest investment outdoor lighting can add speed to your operation.

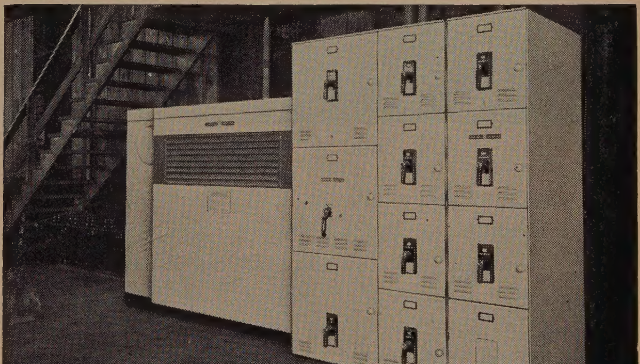
PROTECTION offered by fences and walls can be doubled by adequate protective lighting. Give your plant the protection of a complete lighting system.

GENERAL ELECTRIC

451-161

t this Eastern Plant

dern G-E Metal-clad Switchgear now installed at Traylor Company provides greater safety because parts are completely enclosed. For greater protection inst short circuits, separate circuits are isolated in individual compartments. Circuit breakers may be easily removed for inspection, with protection for personnel. Power is distributed from this unit at 2400 volts, replacing the old 240-volt distribution system.



d-center Unit Substation eliminates long low-tage feeders—saves copper. 2400-volt power is eived at this load-center unit substation and stepped n to utilization voltage on the factory floor. Because the substation is located close to the machines it serves, low-voltage feeders are short, saving copper and giving better voltage control. Discarded cable previously used for low-voltage distribution is shown at left.

GENERAL ELECTRIC

854-35

TRUMAN S. FULLER

Engineer, Schenectady Works Labo
General Electric Company

was elected President of the

American Society for Testing Mate

June 19, 1951

A pioneer in the field of metallu
his 40 years of engineering se
coupled with human understan
has made Truman Fuller a leader
an inspiration to younger engin

(*See Editi*

L. J. Markwardt, Retiring President of ASTM, as he extends best wishes to his successor, Truman S. Fuller

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GENERAL ELECTRIC Review

AUGUST
1951

DEDICATION

E are privileged to carry in this issue of the REVIEW the Engineers' Day Address delivered by ernor Walter J. Kohler on the occasion of the dedi- n of the West Unit of the new Engineering Build- t the University of Wisconsin. *Dedication* is one of most inspiring words. It sums up into a brief ent the aims and hopes and aspirations of a life- . It assembles together all that is good and noble and . It brings into view a panorama of past achievement. it points the way to even better attainment.

is in the schools of our land that the foundations e are laid, together with the home and the church. these foundations are substantial must be our inual purpose. We can be proud of our engineering scientific schools in their accomplishments toward objective. In the past few years with their realiza- of the tremendous upsurge in the demands for uates with technical training and understanding, ngineering schools have everywhere enlarged their ties. We find in one list alone, since 1945, that sixty- engineering schools have added new buildings to ide additionally for 150 departments at an esti- d cost of $50,000,000. And the total must be even than this, a most impressive investment for a ious product.

t it is the teachers who make the schools. All of wisdom, understanding, knowledge; their devo- sympathy, discipline; and their inspiration are e available to the student that he may augment and den his own abilities and understanding. Theirs is minent contribution to all mankind. This con- tion we must protect.

these latter days the engineering profession has particularly concerned that the student be per- d to complete his schooling and that new students engineering schools from the high schools in er numbers. To encourage the high-school grad- s, the Engineering Manpower Commission has lated an explanatory leaflet and copies of the D "Engineering As A Career" to 23,400 high- l principals throughout our land with a contem- d mailing to 25,000 high-school teachers of science mathematics, and to 5600 members of the National tional Guidance Association. The message of the t rings out a critical need—

"The nation needs your help immediately in directing qualified high-school seniors into the engineering schools."

This is two-edged. Substantial student enrollment will not only maintain the supply of engineers but will also keep the faculties intact. Here is a part of our nation's strength which is in grave danger of being weakened. This is work to which the engineers in every community should dedicate themselves.

And the appeal can be on the broadest basis. For in science and engineering the student will find inspiration and service to bring true reward. The thrill of advancing into the unknown to create the new, the satisfaction of knowing that ease has been brought to the bearing of burdens, and the knowledge that wants have been supplied are the heritage of the engineer as he dedicates himself to his life work. In this issue of the REVIEW we see some of these things: a new tube with potentialities of greater efficiency, an advance in measurements to give greater ease of measurement, a new detector to assure better products, a better equipped laboratory for new developments, a fuller knowledge of lighting to assure greater comfort, and a more certain application and maintenance of electric power equipment to achieve even better service. These are but a few in the never-ending procession of contributions which basically continue to make engineering attractive as a profession.

And there is also the opportunity for service in their society affiliations. This month we give recognition to our own Truman S. Fuller, Engineer of the Schenectady Works Laboratory. He has been elected President of the American Society for Testing Materials. Giving of a life devoted to advancing the services rendered to mankind through the knowledge of materials, Mr. Fuller has been honored by the Society dedicated to this same purpose. Through the years it has provided opportunity for the engineer to serve, and the years ahead give opportunity for even greater service as the need for more efficient use of present materials becomes more prominent and the need for new materials ever advances. Of the continual opportunities there is no end.

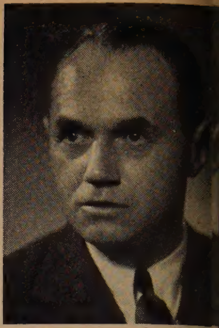
The messages the engineers may bring to the students are filled with individual and group accomplishment; they are filled with opportunities of things yet to be; and they are filled with the concept of community participation by the engineer which Governor Kohler describes in his inspiring address. This is Dedication at its best.

EVERETT S. LEE

LOOK TO THE ENGINEER

Just as the engineer and the scientist are ably meeting the technological challenge of our times, so should they be a compelling sphere of influence in shaping our political destiny for the good of mankind

By WALTER J. KOHLER, JR.
Governor, State of Wisconsin



Governor Walter J. Kohler, son of the late Governor Walter J. Kohler, was born at Sheboygan, Wisconsin, on April 4, 1904. After his graduation from Yale University in 1925, he turned his talents to engineering and ceramic research at the Kohler Company.

The war interrupted Mr. Kohler's career when he volunteered for service in the Armed Forces. He was commissioned a Naval Lieutenant and saw combat as an Air Intelligence officer in the South and Far Western Pacific operations. In October 1945, he was discharged from active duty as a Lieutenant Commander.

Mr. Kohler then resumed his work with the Kohler Company, but in 1947 left to accept the presidency of the Vollrath Company. In 1950, Mr. Kohler was elected Governor of the State of Wisconsin. In addition to his interest in the affairs of government, he is an active participant in community life.

*Governor Kohler's address was delivered at the 1951 Engineers' Day dinner, University of Wisconsin, Madison, Wisconsin, May 4, 1951, following the dedication of the University's new Engineering Building.—*Editor.

IT'S a great pleasure to participate in this third annual Engineers' Day of our University, and to speak to you—the engineers of Wisconsin. In the field of engineering, we—as partners in our University and as citizens in our national civilization—have much for which to be thankful and much for which to be proud today. But we still have much for which we can hope and to which we can look forward. Engineering has earned our thanks, won our pride, and excited our hopes for the future.

Local Achievements

As part of the program for this third Engineers' Day, some of you helped to dedicate this afternoon the west unit of our University's new Engineering Building at Camp Randall. I think we all agree that this new building was long overdue on the campus, just as other buildings—such as the hospital additions, the library, the dairy building, and the home economics addition—now going up have been long overdue. I hope you noticed, as you dedicated the west unit of new "Engineering," that work has now been started on another part of the east unit of this engineering project—the Chemical Engineering Laboratories.

Whether we be engineers, farmers, industrialists, businessmen, professional men, workers in any field of human endeavor, housewives, or boys and girls thinking of preparing for careers in any of these fiel all of us have reason to be proud of the great progr the University has made during these postwar years progress in its physical campus, progress in increasi the quantity and quality of its personnel, especially its teaching and research staff, and—most important progress in all of its great work in education, scie research, and public-service fields.

Nationwide Achievements

The people of our entire nation owe much to y engineers. Our vast industrial civilization has be pretty much of your making. We can take great pri with you, in your work which has brought Amer further along the road to the "table of abundan than any other nation on earth. Winston Churchil few years ago said:

> "If we are to bring the broad masses of the people in every land to the table of abundance, it can only be by the tireless improvement of all of our means of technical production."

That is a simple statement of the technological ch lenge which confronts engineers today as it has in t past, for the improvement in technical production the heart of the engineer's business. It is no accide that America has brought more people to the "table

ance" than any other country. We have more
obiles, more electric lights, more telephones,
radios, more bath tubs, more oil burners, and
leisure—in other words, a higher material stand-
living—than any other nation in the world.

s achievement cannot be attributed to the
ance of our natural resources alone. The Indians
ears ago had more natural resources than we have

l we cannot attribute it to our form of government
Other nations have also provided an atmosphere
lividual economic opportunity, although never
uch productive results as ours.

of Supremacy

one distinct and unique advantage we have is our
's supremacy in technical knowledge. We lead
orld in the number of universities and colleges
ng technical subjects, in the influence of our
cal societies, and in the abundance of our tech-
iterature.

lead also in our willingness to exchange technical
edge among our professions and industries, and
determination to shift burdens from the backs of
o machines. We strive constantly to increase the
ctivity of our people, not through more man-
, but through less human effort and more mechani-

are better-fed, better-clothed, and better-housed
iny other people on earth. Our health as a nation
aralleled and it is constantly and phenomenally
ving—our life span grows longer every year.

helping to raise our standard of living, our engi-
have helped make it possible for us to have the
and the leisure to attain a continually higher
of culture.

h less than seven percent of the world's popula-
we have more young people in high schools and
es, more musical and literary organizations, more
es, and more distribution of the written and
word than all of the other ninety-three percent
ned.

have more hospitals, more charitable institutions,
probably, more churches per capita than any
country.

d Neglected

erica's engineers of yesterday and today have met
chnological challenge of their times. But what
the political challenge? There exists a vast gap
ting technology and politics. With few exceptions,
he engineer and the physical scientist hold aloof
ll but the technical life of our times, remaining
wholly detached from its politics. With engineers and with scientists, it is their status as professional men that counts; status as a citizen participating in public affairs receives little consideration.

In any democratic society there are many questions requiring broad public discussion in which specialism of any kind has only a limited place. Such matters include: civil liberties; the field and function of pressure groups; public health; child labor; international relations; monopoly; electoral reform; racialism; relief for the blind or indigent; labor relations; community organizations; conservation; free-enterprise system; public schools; fiscal policy; taxation; civil service; regulation of public utilities; public administration; the tariff; and farm policy.

It is a denial of the democratic process when those upon whom some of the best educational techniques have been expended do not have a closer acquaintance with, and take a more active part in, the public discussion of some of these matters. Yet, I think, it is rather unusual for either engineers or scientists to take such a part except as the technical spokesman.

With the obvious exception of lawyers, the attitude of professional men generally toward politics and politicians seems to account largely for their aloofness from participation in community responsibility. In deprecating politics and politicians, engineers and scientists as groups have necessarily become disassociated from the life of the people.

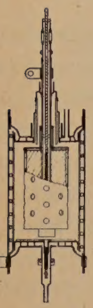
Effective Application of Engineering Principles

However distasteful it may be, technicians must learn to live with those political agencies through which the results of their labors are brought into being for the benefit of the people. The engineers with the scientists—including the social scientists—have all the tools that now exist. While we need more science and better engineering, we need even more the prompt and effective application of that which we have.

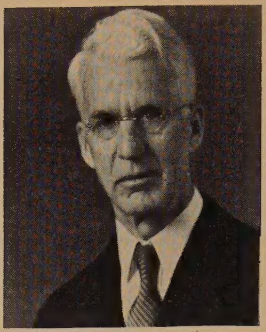
Our nation and all other free countries of the world are facing many social, political, and economic decisions of crucial importance for the future of civilization. We greatly need the logical analysis and factual, dispassionate reasoning of engineers and scientists to help us make those decisions soundly for the good of mankind. Engineering and science can help humanity find the right political way now, as they have helped find the right technical way in the past, by closing completely the gap between technology and politics and public life.

I have the utmost confidence that engineers will become increasingly aware of this real and urgent challenge—and true to their high tradition—will ably meet it.

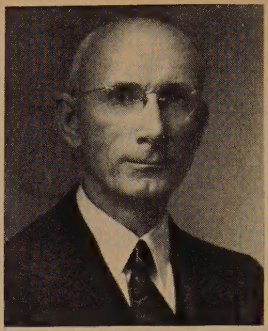
THE CESIUM-VAPOR RECTIFIE



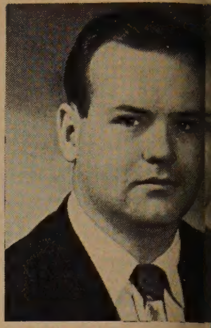
By
Dr. A. W. HULL
E. E. BURGER
R. E. TURRENTINE
Research Laboratory
General Electric Company



Albert W. Hull



Emmett E. Burger



Richard E.

THIS is a new type of hot-cathode vapor rectifier, in which cesium-vapor functions both as conducting gas and thermionic coating material. The cathode is of the conventional type used in thyratrons, namely a multicellular structure of nickel vanes, surrounded by a heat shield. However, it differs from conventional cathodes in that the vanes are uncoated except by the monatomic film of cesium which is continually reformed by condensation. The tube must be heated to approximately 160-180 C during operation, to maintain the desired vapor pressure of 0.015-0.035 mm.

Cesium is unique in having the lowest ionization potential and the lowest thermionic work function of any known element. Hence one was led to expect optimum efficiency from this dual use of cesium. This expectation has now been realized, the over-all efficiency at 250 volts being better than 98 percent for the developmental tubes tested. Typical values are: cathode heating power, 280 watts; peak electron emission, 2800 amp; voltage drop at 600 amp, 3.30 volts.

In 1922, J. M. G. Mackay and E. E. Charlton(1) conceived the idea of making a vapor rectifier of the hot-cathode type in which cesium acts as both conducting vapor and thermionic coating material. This dual use of cesium offered some very attractive features. Cesium vapor has the lowest known ionizing potential, 3.88 volts, and hence promises the lowest possible arc drop. Secondly, cesium has the desired vapor pressure of 0.015 to 0.035 mm in the temperature range of 160 C to 180 C.(2) This requires heating the whole tube, but has the advantage that it facilitates air cooling. Thirdly, at these vapor pressures, the equilibrium between condensation and evaporation maintains a monatomic layer of cesium on a metal surface at 750 C(3) and gives it the most efficient electron emission of any known cathode. Finally, the life of this electron-emitting surface should be unlimited, since the cesium coating is renewed continually and the cathode temperature is so low that cathode metals like nickel do not evaporate appreciably. Hence a rectifier embodying these features promised the closest possible approach to the ideal of 100 percent efficiency and infinite life.

This ideal proved difficult of accomplishment bec
a glass-metal seal could not be found that would
stand cesium vapor. At 200 C, which is the seal
perature that is likely to be encountered, cesium v
quickly reduces the oxides of all known glass-se
metals, thus destroying the bond between metal
glass and causing the seals to break or leak. Mod
success was attained with seals made in hydrogen
seals using platinum, but these lacked mecha
strength.

Several years ago, there was developed(4) in
Research Laboratory a method of soldering cerami
metal, with titanium hydride as bonding agent.
made by this method, using silver-copper eutect
pure copper as solder, were found to be uninjure
exposure to cesium vapor at 400 C for 100 hours.
test is equivalent to 100,000 hours at 200 C if, as is
of many chemical reactions, the rate doubles eve
deg C. Of the various metals tested, gold was foun
be quite soluble in cesium, silver less so, silver-co
eutectic very slightly, while copper, nickel, and iron
entirely unattacked. This points to copper as a desi
solder, and nickel and iron for structural material

With this solution of the seal problem, developm
tubes have been developed and the predicted efficie
have been realized.

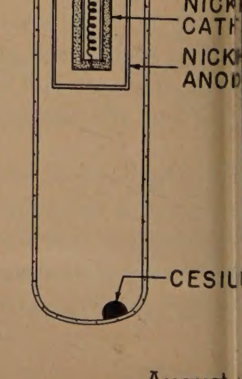


Fig. 1. Tube used for study of electron emission in cesium vapor

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(1) Numbered references are listed at the end of the article.

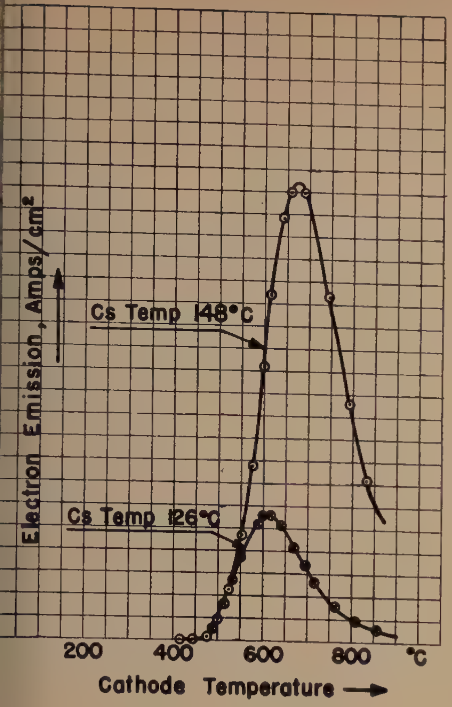


Fig. 2. Variation of electron emission with temperature in cesium vapor

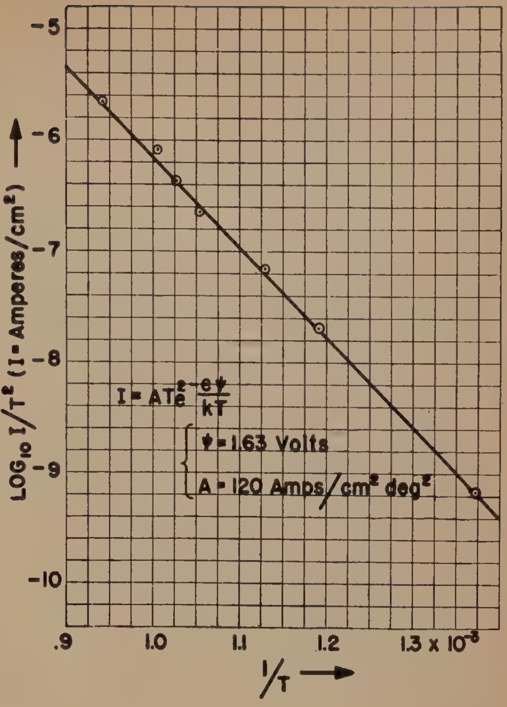


Fig. 3. Richardson plot of electron emission from a nickel cathode coated with 0.67 monatomic layer of cesium

ron Emission in Cesium Vapor

reliminary measurements of electron emission and age drop were made with the tube shown in FIG. 1. cathode is a thick-walled nickel cylinder, ½ in. neter by 1½ in. long, with a ¼-in. axial hole which mmodates a tungsten heater surrounded by a thoria lator. The thick wall assured uniform temperature he cathode and allowed the temperature to be sured by a thermocouple welded to the surface. The ım-vapor pressure was controlled by immersing the le tube in a bath of silicone oil, which was stirred by oling air through it.

ypical electron-emission data are shown in FIG. 2. y agree well with the values predicted by Taylor Langmuir(3) from their study of tungsten filaments ow-pressure cesium vapor. The current increases dly with cathode temperature, passes through a imum, and then falls off as the temperature be- es too high for a monatomic layer of cesium to be ntained. These data were taken with six volts be- n anode and cathode, which was found to give oximately saturated emission current (cf. FIG. 4). ngmuir and Taylor,(3) working at lower cesium peratures, found that the maximum electron emis- from tungsten occurred when the cesium coating less than a complete monatomic layer, namely at of a monatomic layer. Assuming the optimum ng to be the same for nickel as for tungsten, a plot ese maxima against the reciprocal of cathode tem- ture constitutes a *Richardson plot for a nickel de coated with 0.67 of a monatomic layer of cesium.* a plot is shown in FIG. 3. It yields a work function 3 volts, with an *A* value of 120 amp/cm² deg². This esponds to an emission of 1 amp/cm² at a cathode perature of 740 C and a cesium-vapor pressure of mm (cesium temperature 185 C).

FIG. 4 shows current vs. voltage-drop data for a cesium temperature of 180 C (vapor pressure = 0.035 mm). It will be noted that 50 percent of the saturated emission current can be drawn at a voltage drop of one volt, and 85 percent at two volts.

Design Features

The structure of a developmental cesium rectifier, designated as Tube 103, is shown in FIG. 5. Its essential features are a heat-shielded multicellular cathode, surrounded by a stainless steel cylinder 4¾ inches in diameter which acts as anode, and about a gram of cesium metal.

Structure of Cathode

The cathode consists of clean, uncoated nickel vanes, arranged radially and welded at their inner edges to the nickel tube which forms the cathode current lead. The

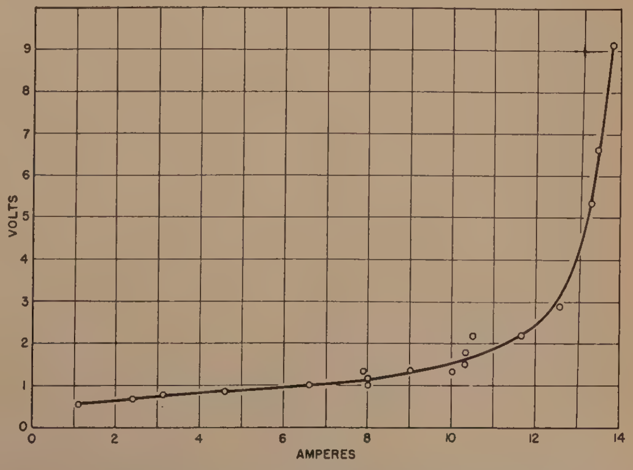


Fig. 4. Electron emission and voltage drop in tube shown in Fig. 1, at cathode temperature 725 C and cesium temperature 180 C (vapor pressure = 0.035 mm). The cathode area is 18.0 cm²

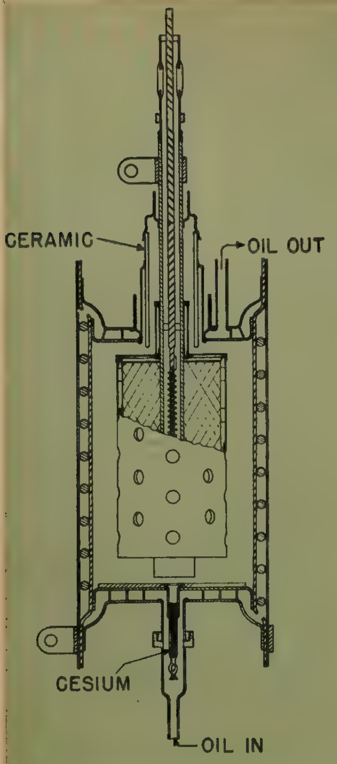


Fig. 5. Developmental cesium vapor rectifier (Tube No. 103)

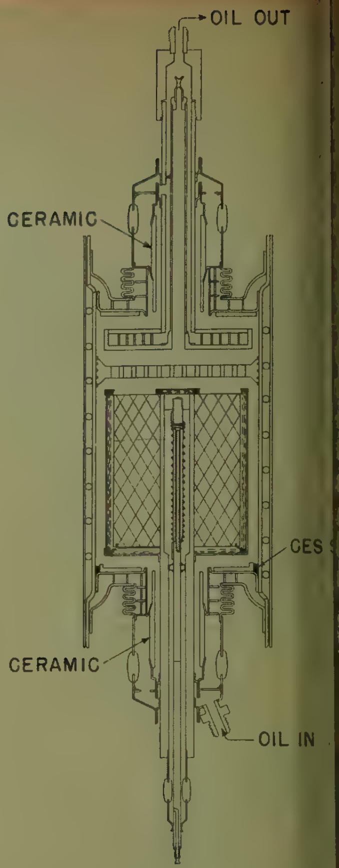


Fig. 6. Cesium thyratron with conduction-cooled grid

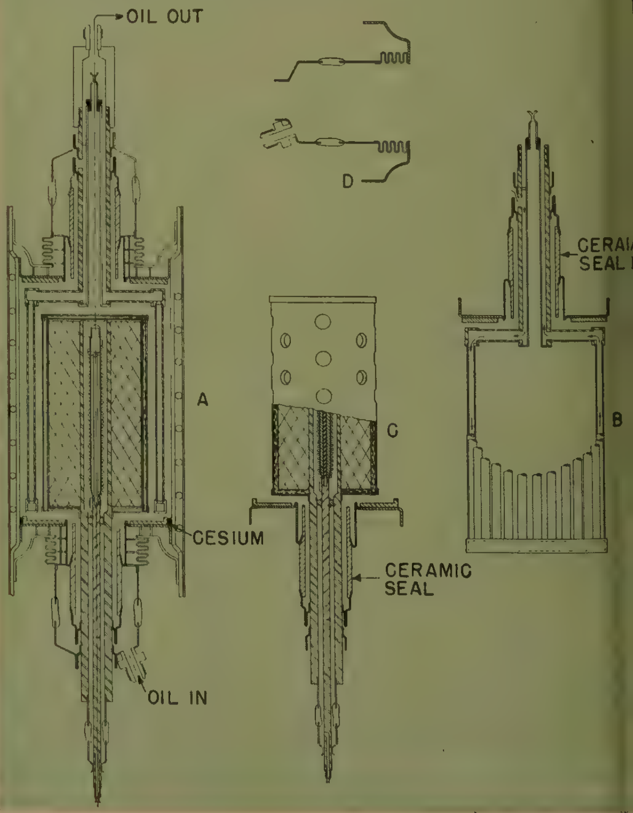
tube is closed at its inner end and is exhausted separately, thus excluding cesium and allowing an ordinary glass seal to be used for the filament lead. This structure avoids a possible short circuit of the filamentary heater by condensed cesium on the insulator or by a low-voltage arc between filament leads.

In order to obtain large electron emission with minimum heat loss, the electron-emitting area of the vanes is increased by welding nickel gauze to both sides of each vane. The vane assembly is surrounded by several layers of 0.0007-in. nickel foil, embossed by prick-punching to reduce the contact area, and rolled into a cylinder, the whole being surrounded by a 0.030-in. nickel cylinder. A number of equally spaced holes, about ⅜ in. in diameter, are punched in this heat shield for exit of the electrons. The number and size of the holes is a compromise between heat loss and current limitation due to the limited cross-sectional area of the holes,⁽⁵⁾ the best value being such that the holes are just able to carry the current which the cathode emits. Under the conditions of our tests, the optimum hole area is about ten percent of the heat-shield area.

Insulation of Cathode

A ceramic cylinder supports and insulates the cathode. It is soldered to spinnings of nickel-iron alloy by the titanium hydride process.⁽⁴⁾ The form of this seal provides a long insulating path over the inside surface of the ceramic, while its location—around the cathode stem—provides automatic means for heating the ceramic to avoid condensation of cesium. Later it was found desirable to control the temperature of the upper portion of the ceramic by including it in the circulating oil system (cf. FIG. 7).

Fig. 7. Thyratron with liquid-cooled grid (Tube 109). *A*, complete asse bly; *B*, grid; *C*, cathode; *D*, oil header



l of Anode Temperature

anode temperature in cesium-vapor rectifiers be more narrowly limited than in mercury tubes: st be above the condensing temperature of the n, 170 C, and below about 400 C, where electron on becomes appreciable. This control is accom-d by circulating a fluid at the proper temperature ll the surfaces—seals, anode, and grid—in series, hence through a radiator provided with a fan. ne oil has been used for this purpose. A Calrod* around the tube heats the oil initially, and a thermostat actuates heater or fan to keep the rature of ingoing oil constant. In this way the rature which controls the vapor pressure of the n is maintained constant within 1 or 2 deg C, while ner parts of the tube are at a higher temperature. of 20 deg C or more in outgoing oil temperature e satisfactory.

ure of Grid and Anode

only problem involved in the use of a grid is that ping its temperature within the allowed limits, obviously are the same as for the anode. A thyra-f conventional form with conduction-cooled grid, ated as Tube 106, is shown in Fig. 6. The grid is per disk ¼ inch thick, bored with ¼-inch holes ilver-soldered to the metal cylinder. This design d unsatisfactory for large currents because of the lty of controlling the grid temperature. For ex-, at 50 amp average current it operated properly, complete phase control. With currents of 120 average, control was obtained only for short ls of running because the grid soon got hot enough it electrons, which caused it to lose control.

improved design of thyratron with liquid-cooled lesignated Tube 109, is shown in Fig. 7. The grid nposed of metal tubes through which the circulat-l flows. The cathode and grid portions of this tube C and B) are shown assembled on the headers, to be welded into opposite ends of a cylindrical ppe. An oil header, shown as part D, is then welded h end, which completes the assembly, allowing oil-g of all parts of the tube. The complete tube is n at A.

o additional rectifier Tubes, 105 and 107, were with the same anode structure as Tube 103 but arger cathodes, to obtain data on voltage drop at currents. In Tube 105 the cathode diameter was sed from 3¼ in. to 4¼ in., and the number of from 12 to 24, thus increasing the electron-ng area from 2300 cm² to 5600 cm². The close ng of the vanes makes it doubtful that the whole s area was utilized, because of the difficulty of g the electrons out of the narrow spaces. In Tube his area was further increased to 8700 cm² by sing the length of the cathode, keeping the di-r and spacing of the vanes the same. Appropriate ses were made in the number of holes in the heat shields. (Data on these tubes are given in Figs. 10 and 11).

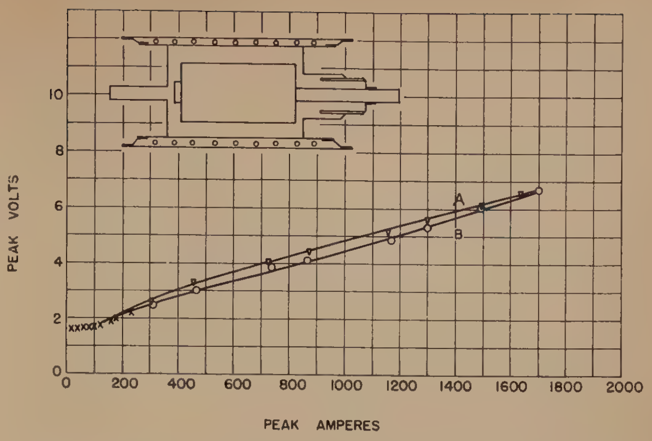


Fig. 8. Volt-ampere characteristics of Tube 103 at cesium temperature 170 C. Curve *A* is for cathode heating power 225 watts; curve *B*, 280 watts

Test Data

The two most interesting features of the cesium tube are its (1) low arc drop and (2) high electron emission.

Arc Drop

Fig. 8 gives typical voltage drop vs. current data for the tube shown in Fig. 5 (Tube 103). The values up to 230 amp were obtained from direct-current operation; the data for higher currents were obtained from three-phase alternating-current operation at 110 volts, using a magnetic oscillograph. It is seen that the voltage drop is much higher than that shown in Fig. 4. This is attributed to the long, restricted path of the electrons, made necessary by the heat-shielding. The total loss, namely, the sum of heating power and arc drop, can be calculated from the data in Fig. 8, and is shown in Fig. 9. The calculations assume that the tube carries constant current for one third of each cycle, so that the appropriate arc drop is that corresponding to three times average current.† It is seen that the loss, and hence the efficiency, is practically independent of heating power over a 25 percent range, higher heating power being compensated by lower arc drop. The loss is also nearly independent of load over the range from 100 to 400 average amperes.

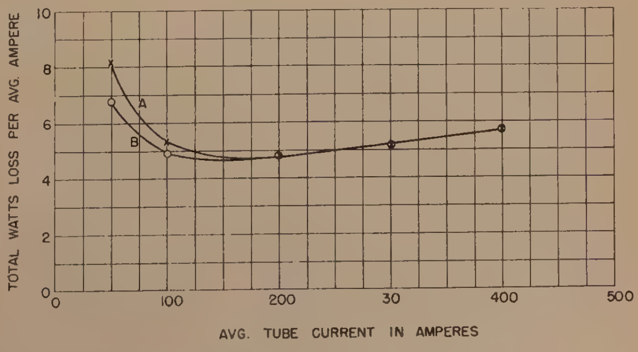


Fig. 9. Total loss per ampere vs average current per tube, in 3-phase operation. Curve *A*, cathode watts 280; curve *B*, 225 watts

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*trade-mark of G.E. Co.

†The effective arc drop in three-phase operation is slightly less than this because of the overlap of current during commutation.

Similar volt-ampere data for Tubes 105 and 107 are shown in FIGS. 10 and 11. The data are from oscillograms taken after about 1 second of operation, except those represented by an asterisk (*), which were taken after one minute. It will be noted that the voltage drop is lower at the higher vapor pressure. The decrease at high pressures is much less than in the case of gases such as argon and mercury, which have metastable states and are capable of two-stage ionization. The voltage drop also decreases with increase of cathode heating power, up to the highest values used. This was unexpected, and is interpreted as the result of nonuniformity of temperature, such that only part of the cathode is at the optimum temperature at any given wattage; at the highest wattage the part at optimum temperature is the outer portion, including the
of the heat shield, whose proximity to the ano
responsible for the low voltage drop.

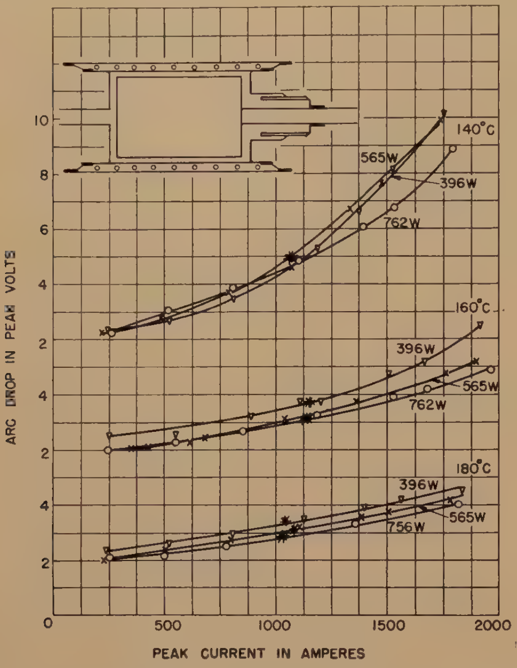


Fig. 10. Volt-ampere characteristics of Tube 105, for cesium temperatures 140, 160, and 180 C (pressures 0.0055, 0.015, and 0.035 mm respectively). Curves *A*, 400 watts cathode heat; curves *B*, 565 watts; curves *C*, 760 watts. The asterisks (*) represent readings after one minute's running

The abnormal voltage drop in Tube 107 will be
mented on later.

FIG. 12 shows the total loss per ampere (average
Tube 105. The loss is nearly constant over the
from 200 to 600 amp average current (600 to 1800
peak), and for cathode heating power from 400 to
700 watts, and is about five watts per ampere (aver
This corresponds to an efficiency of 95 percent at
volts, or 98 percent at 250 volts.

FIG. 13 shows volt-ampere data for the thyra
shown in FIG. 8 (Tube 109). These data were take
Electronics Department of the General Electric
pany in the course of three-phase load tests on
tubes. A slight modification of standard AIEE
procedure was used for voltage drop, and gives
voltage drop vs. *average* tube current. These value
nearly the same as those for Tube 103 (see FIG
whose cathode is identical with that of Tube 109,
ing that the addition of the grid does not increase
voltage drop very much.

Electron Emission

Data on electron emission were obtained from os
grams taken during short-circuit tests on the a-c p
supply. When the current through a thermionic tu
increased beyond a certain value, the voltage drop
rapidly because of the inability of the cathode to
nish enough emission. For cesium tubes, the limi
emission has been taken arbitrarily as the current
responding to a 15-volt arc drop. At voltage drop
high as 20 or 30 volts, cathode spots form on the out
of the heat-shielding of the cathode and furnish
additional abnormal emission.

For Tube 103, at a cesium temperature of 170 C
280 watts cathode heat, the maximum electron emis
as defined above was 2850 amp. This corresponds t
electron emission of 1.25 amp/cm^2 from the 2300 c
cathode area, and an emission efficiency of 10 amp

Fig. 11. Volt-ampere characteristic of Tube 107, at 160 and 180 C cesium temperatures (Curves *A* and *B* respectively). The high drop at 160 C is attributed to the magnetic effect of the current in the cathode stem

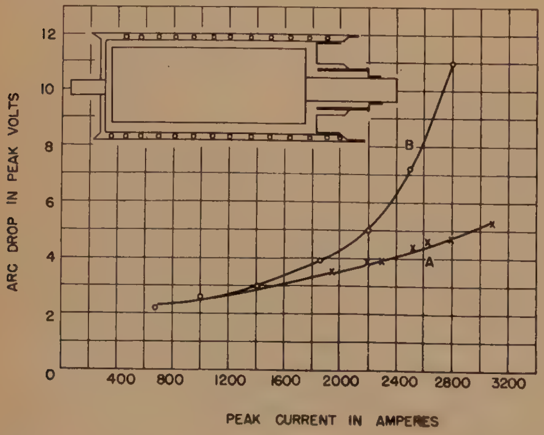
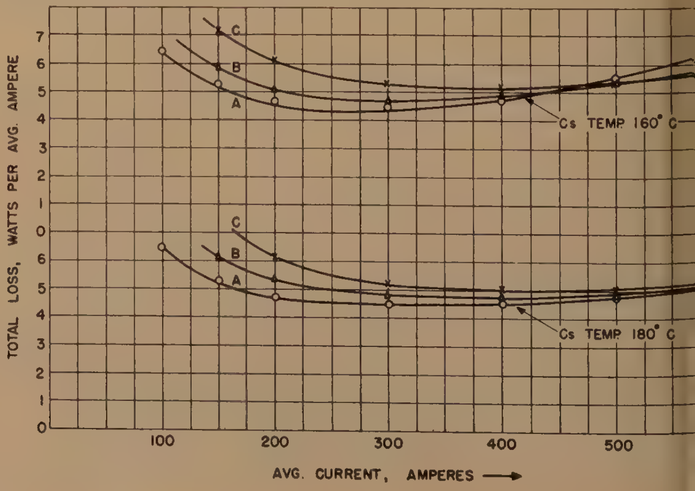
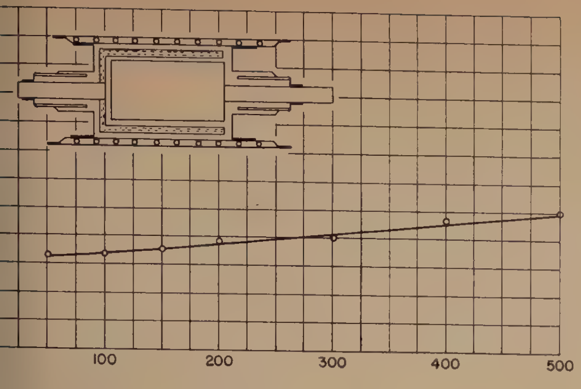


Fig. 12. Total loss per average ampere in Tube 105. Curves A are for 400 ca
watts; curves *B*, 565 watts; curves *C*, 760 watts





Volt-ampere characteristic of thyratron shown in Fig. 8 (Tube
160 C cesium temperature (0.015 mm) and 240 watts in cathode

f heating power. This *apparent efficiency* is much
than 100 percent since, as is well known, each
e of electron emission carries away an amount of
qual to the work function. For cesium on nickel,
1.63 watts per ampere, which is more than 16
the total externally applied heating power at
ium load. Hence it is evident that the applied
g power can furnish little more than the standby
ion losses, and that practically all the heat re-
for extracting the electrons must be furnished by
ode circuit in the form of radiation and impact of
l atoms and ions. These energy losses are included
voltage drop.

s mechanism of cathode heating calls for a rather
alance between "back heating" and electron-
tion cooling in order to maintain a nearly con-
cathode temperature, which is especially im-
t in cesium tubes since electron emission falls off
with either increase or decrease of temperature
G. 2). Oscillograms taken with Tube 105, (1) im-
tely after closing the circuit, (2) after one minute's
g (see FIG. 10), show no difference in arc drop,
ith average currents of 400 amp (1200 amp peak).
ndicates a satisfactory balance for this tube. It is
rked contrast to the behavior of mercury-vapor
of similar construction, in which the back heating
exceeds the cooling.

mitation and Magnetostriction

s well known, electron emission is not the only
of current limitation in gaseous rectifiers. Another
e cause is the *gas limit*, namely, the product of
density and total minimum cross section avail-
r the discharge. In this case, the limiting cross
is the area of the holes in the heat shield; for
103 this area is 30 cm². By extrapolation from
us measurements(5) the maximum current density
cury vapor at 0.023 mm is 100 amp/cm². The
ed cesium current density of 2850/30 = 93
m² is therefore close to the gas limit, assuming
sium and mercury behave similarly in regard to
ximum degree of ionization.

e is a third limiting mechanism in high-current
namely, the effect of the magnetic field of the
itself. Such an effect has long been suspected in
mercury-vapor tubes, but never confirmed. The voltage-drop data in FIG. 11 suggest strongly that such a limitation exists in the case of Tube 107. As noted previously, the cathodes in Tubes 107 and 105 are identical except in length, the ratio of lengths being 1.56. Hence one would expect the voltage drop in these tubes to be the same when the currents and heating powers are in this ratio; for example, the voltage drop in Tube 107 at 2800 amp and 1000 watts should be the same as that of Tube 105 at 1800 amp and 700 watts. A comparison of FIGS. 10 and 11 shows that this is far from true.

At high cesium temperature (curve *A*, FIG. 11, and 180 C curve in FIG. 10) the voltage drops are more nearly equal, being 4.9 and 3.9 volts respectively. At 160 C (curve *B*, FIG. 11, and 160 C curve in FIG. 10) they are 11 and 4.5 volts respectively. It is possible that the difference in voltage drop in the two tubes is due to the inhibiting effect of the stronger magnetic field of the longer cathode, this effect being the greater the lower the vapor pressure, because of the longer mean free path of the electrons.

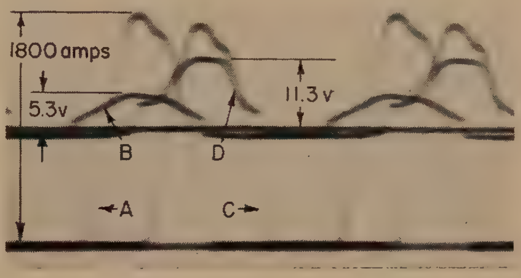


Fig. 14. Increase in voltage drop in Tube 105 produced by a magnetic field of 188 gauss. Traces *A* and *B*, current and voltage drop without field; *C* and *D*, with field. The field increases the drop from 5.3 volts to 11.3 volts

Consider the portion of the cathode nearest the terminal. A current of 2800 amp flowing into the cathode along the stem (diameter of stem 1 in., width of each vane 1⅜ in.) would produce a field of 450 gauss at the inner edge of the vanes, 185 gauss at their center, and 120 gauss at their outer edge.

The effect to be expected from such fields was tested by surrounding Tube 105 by a solenoid ten inches in diameter and 10 inches long, wound with 340 turns. A current of 15 amp in this coil produces near its center a field of 188 gauss. This is the same as the field produced at the center of the vanes by a current of 2800 amp, both being at right angles to the direction of electron flow. The voltage drop with and without this field is shown in the oscillograms of FIG. 14. It is seen that the voltage drop at 1800 amp is increased by the magnetic field from 5.3 volts to 11.3 volts. The fact that the enhanced voltage drop is the same as that in curve *B*, FIG. 11 is coincidental, since the geometry of the fields is far from identical. The important fact is that the effect is large. The data indicate strongly that when the current in the longer Tube 107 approaches 2800 amp, the part of the cathode nearest the terminal is largely prevented from contributing to the emission by the magnetic field of the current along the stem.

At a still lower cesium temperature, 140 C (0.0055 mm), the effect of a solenoid field of 188 gauss was enormous, increasing the drop from 4 volts to 24 at a current of only 250 amp peak. An unexpected effect of the solenoid field in this case was that it caused instant arc-back in three-phase operation, even at 110 volts, with currents as low as 15 amp peak and a resistance load. The arc-back may have been caused by interference with deionization, since it did not occur in single-phase operation. It is significant because no arc-backs were observed during the normal voltage-drop tests described earlier, using three-phase voltages of 110 and 220 and currents up to 1800 amp peak, nor in the load tests at normal loads.

Load Tests

Load tests were made by the Tube Division of the Electronics Department of the General Electric Company in a standard test set, using a delta three-phase, wye power circuit with 264 volts rms phase voltage and a load voltage of 309 volts d-c. Since only one cesium tube was available for each test, sealed ignitrons, Type GL-507, were used in the other two phases.

Tubes 103 and 109 passed all the tests for a 200-amp normal rating without arc-back. These tests included an 8-hour run at 200 amp, 2 hours at 300 amp, and 1-minute peaks at 400 amp. The maximum instantaneous current was about 3000 amp.

Tubes 105 and 107 operated satisfactorily at 400 amp, but would not carry the 50 percent and higher overloads.

Tube 109 showed normal grid control up to 100 amp average current, requiring only 4 volts negative grid potential to prevent starting. It was observed, however, that the insulation-leakage current over the ceramic insulator required a stiff grid-control circuit. At 200 amp average current, the grid would control for only a very short time, indicating either excessive insulation age or electron emission from some structural me which was being heated by the discharge.

Test Results

These tests prove that the low voltage drop and electron emission which are characteristic of cesium be utilized in gaseous rectifiers to give high effici and reliable operation. The results indicate that, proper design, cesium rectifiers and thyratrons ca built for any desired currents and for voltages at as high as 300.

Two design features requiring special attention electric leakage over ceramic insulators in cesium and the effects of magnetic field. It is believed cesium-resistant ceramic materials can be found w will obviate the leakage problem. The effect of mag field merits further study. But it is to be noted that effect was observed when *large* currents were cro into a *small* tube, and hence it probably can be avo by proper design; it was inappreciable at current sities such as those used in conventional mercury-v tubes.‡ Such magnetostrictive effects are not to b pected in cesium tubes of high current rating if the housed in envelopes of appropriate size, namely, a comparable to that of mercury tubes of similar ra

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While these tubes have been produced in the labora none of them have been placed in commercial produc

References

(1)U.S. Patent 1,648,458, Nov. 8, 1927.
(2)J. B. Taylor and I. Langmuir, *Phys. Rev. 51*, 753–760, 19
(3)J. B. Taylor and I. Langmuir, *Phys. Rev. 44*, 423–458, (see Fig. 15, p. 438).
(4)R. J. Bondley, *Electronics 20, Pt. 2*, 97–99, July 1947.
(5)A. W. Hull and F. R. Elder, *Jour. App. Physics 13*, 376,

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‡All the tubes described in this article were housed in the envelope FG-238-B ignitron, whose rated current is 200 amp average. Tubes and 109, which were tested at this rating, showed no magnetic effects.

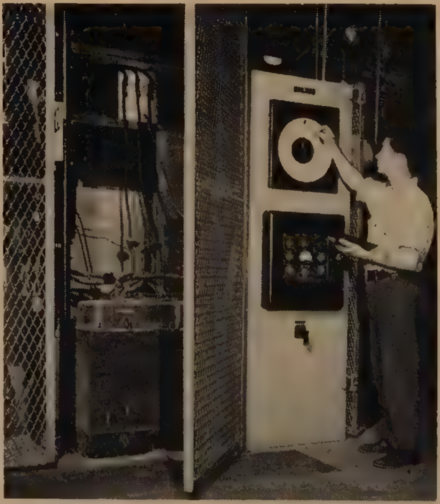
HIGH LIGHTS AND SIDE LIGHTS

Nylon Fabric Continuously Set by Radiant Heat

A nylon-setting machine has recently been developed which permanently sets nylon tricot fabric at a continuous rate of 16 yards or more per minute.

Designed to be installed on existing tenter frames, the new machine consists of aluminum reflector units housing Calrod* tubular heaters. Automatic temperature control is provided by Reactrol*, an electronic temperature-control unit which allows automatic stepless heat adjustment through thermocouples located in the reflector frames. Although 16 yards per minute is the machine's average speed, higher speeds can be accomplished by additional reflector units.

Operating costs are reported to be less than $1.00 per hour. Compared with autoclave and other methods, radiant-heat setting requires only five instead of ten steps, and the width of the set fabric is constant. Dyeing can be done either before or after setting, and the radiant method is continuous instead of Since the material is set while still o tenter frame, extreme accruacy in di sion is obtained.


Automatic temperature control with stepless heat adjustment for the new nylon-setting machine is provided by this Reactrol control system (safety panel opened for photo)

In operation, the Reactrol tempera indicating controller is set at the p termined setting temperature of the f just before the tenter drive is started new machine is electrically co-ordi with the tenter drive to make the oper automatic. To prevent scorching, reflector frames are designed to matically rise if flow of fabric throug tenter frame stops.

The machine was designed with ficient temperature range to treat synthetic fabrics and has numerous sible applications in both the textil paper industries.

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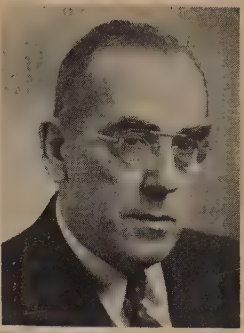
*Reg. trade-mark of G.E. Co.

SWITCHGEAR DIVISIONS LABORATORY

The expanded and modernized facilities indicate the breadth of an industrial Laboratory's functions and activities. The ultimate objectives—product improvement and satisfied users—are achieved by thorough planning, high-calibre personnel, adequate facilities, co-ordination of groups served, and the co-operation of other Laboratories



By A. E. ANDERSON
Engineer, Switchgear Divisions Laboratory
General Electric Company

A. E. Anderson

HE tremendous growth in size and number of ndustrial Laboratories reflects not only their contributions to new and better products and es, but also indicates the extent to which Labora- have become a permanent and essential part gressive industrial enterprise.

Switchgear Divisions of the General Electric any in line with these trends have recently ex- d and modernized their Laboratory facilities and ed its staff, to insure adequate technical resources e future growth and success of the switchgear ess. This Laboratory is one of 25 main laboratories ed to the various operating departments of the any.

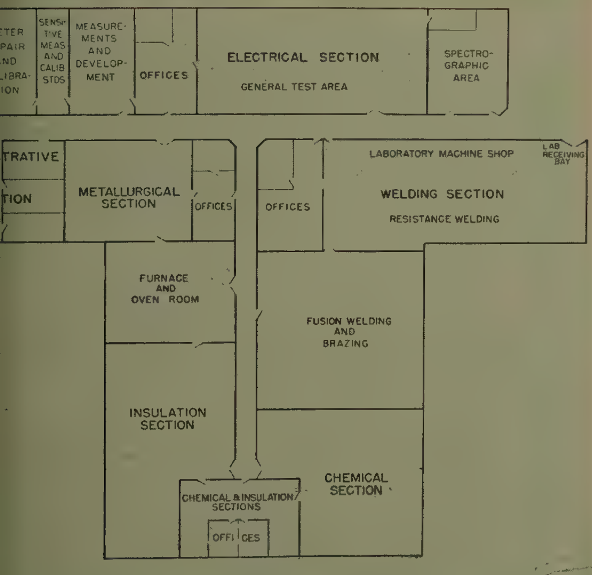


Fig. 1. Plan view of Switchgear Divisions Laboratory

m both the physical and organizational points w, the Laboratory is divided into five sections: y, Chemical; Electrical; Insulation; Metallur- and Welding, each with its own working area, as in Fig. 1. Grouped in each of these areas are espective personnel and required facilities and ment. A minimum of subdivision is used in each n, since one of the underlying thoughts was to as much flexibility as operating conditions would t. The total area shown in Fig. 1 is more than that formerly occupied. Moreover, the location of the Laboratory permits further expansion should conditions warrant this procedure.

An expansion program, of the kind recently concluded, provided an excellent opportunity for studying the existing conditions of operation of the Laboratory, as well as for looking into the future for new or modified requirements. In the course of the study, a number of Laboratories were visited to obtain additional ideas or suggestions.

The nature of switchgear design and manufacturing is such that considerably more than one-half of the technical personnel of the Laboratory has been educated in nonelectrical fields. This is a further indication of the valuable contribution being made by men trained in mechanics, physics, chemistry, and metallurgy. They form a valuable complement to the electrical engineers in this field of electrical manufacture.

Objectives and Facilities

The Laboratory should be in a position to render prompt service and guidance to both Engineering and Manufacturing through applied research and development. Its activities should aid in the development of new products and an improvement in quality and reduction in cost for established products. Among other things, this requires the investigation, evaluation, and development of new materials, processes, and associated instrumentation.

To accomplish these objectives, and to meet the needs of the switchgear business, modernized facilities and equipment have been provided. These are flexible enough to readily take care of future trends and to permit expansion in all the Sections.

For example, in the Fusion Welding and Brazing Area, as illustrated in Fig. 2, there is provided the low wall-mounting of electrical, water, sewer, air, and gas services. These services, which extend around four sides of the room, permit quick connection of welding equipment and also enable rearrangements to be made readily.

In the Electrical Section, the use of overhead conduit permits rearrangements to be made more readily than where conduits are located in the floor.

A number of overhead cranes are installed throughout the Laboratory wherever heavy or large work or material has to be handled (See Figs. 2 and 6).

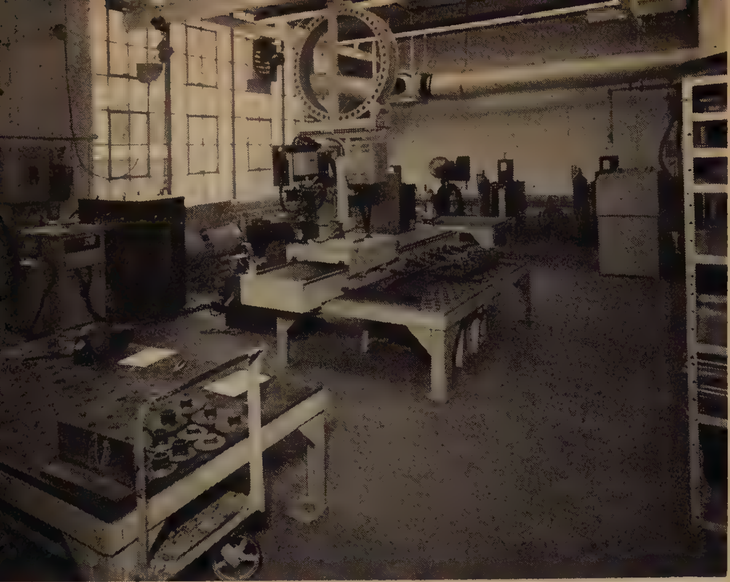


Fig. 2. Interior of Fusion Welding and Brazing Area. Facilities provided around sides of room permit quick connection of equipment to air, water, electrical, and other services. Room exhausted directly to outside of building

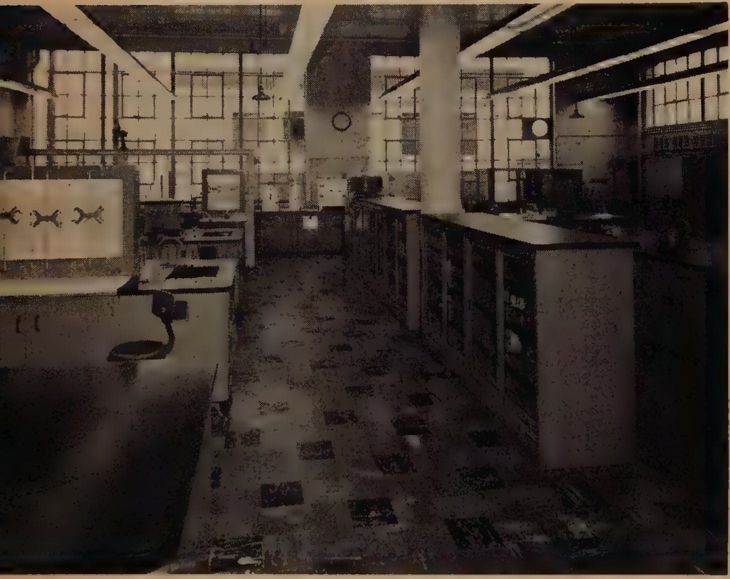
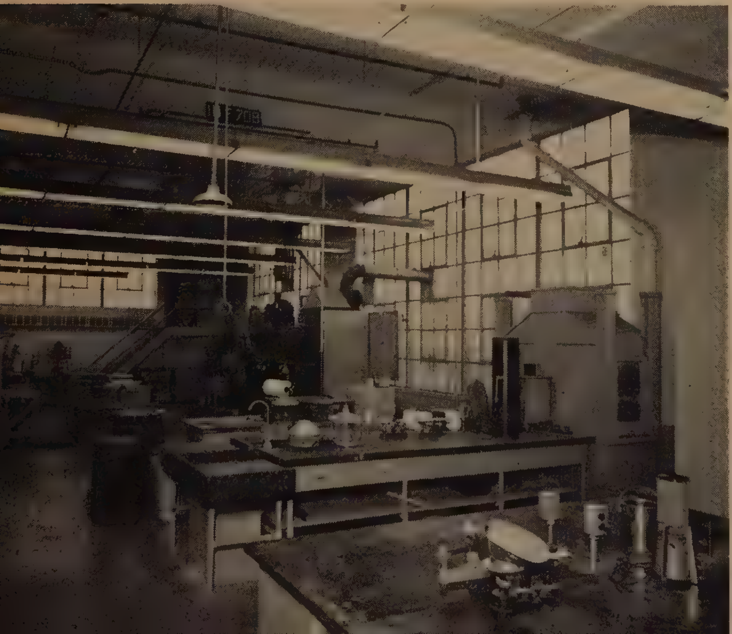


Fig. 3. General view of working area of Chemical Section. Equipment for analytical work shown at left; for organic and inorganic finishes at right

Fig. 4. General view of working area of Insulation Section



Generally, the electric power supply to the Labo
tory comes from various factory services or from
own machines. In addition to these, the retention
certain transfer lines—installed by the former occupa
of the area—enables the Electrical Section to ma
plant-wide connections to a number of substations,
which are located a wide variety of machines. Th
machines are used at infrequent intervals. The trans
lines, in effect, enable the Laboratory to expand t
type of service without the need of further investme
or increase in space.

Safety and good housekeeping require major atte
tion in the operation of a Laboratory. An example
safety features is the inclusion of a pair of emergen
push buttons at each of the general-purpose test tab
installed in the Electrical Section. One of these butto
removes the power supply to the local area served
the respective test table, while the other removes t
power supply to the entire Section.

In addition, the three high-potential a-c test are
of the Electrical Section are provided with the cu
tomary interlocking that requires the gates to be clos
before high voltage can be applied. Although certa
testing functions are normally assigned to each of th
three areas, it is also possible to combine them in
one or two larger areas by removing two or one grou
of separating grilles, respectively. The system is
ranged in such a manner as to provide interlocki
circuits which retain the same protection regardless
whether the entire space is functioning as one, two,
three areas. This arrangement permits segregation
work that relates to the normal operation, and yet
flexible enough to accommodate at infrequent interv
relatively large apparatus which may require hig
potential testing.

In the Chemical and Insulation Sections (Figs.
and 4) there are provided such features as induced-dr
systems and emergency spray heads, which opera
independently of the local water pressure. Anot
example is the use of individual ventilating units
each of the darkrooms. Additional safety features
present in the various Sections, either as perman
installations or adjuncts to temporary set-ups.

The areas marked Furnace and Oven Room a
Fusion Welding and Brazing (Fig. 1) are enclosed a
separated from the remainder of the Laboratory; th
are exhausted to the outside. In this manner, su
heat and fumes (and resulting dust) as otherwise wo
have been present in the adjoining portions of
Laboratory are carried directly outside the buildi
This procedure leads to improved working conditio
and is conducive to good housekeeping. Fig. 2 sho
one of the two window-mounted fans for exhaust
the Fusion Welding and Brazing Area. Fig. 5 shows
interior of the Furnace and Oven Room, shared join
by the Insulation and Metallurgical Sections. The h
and fumes from this area are exhausted in the sa
manner as that shown in Fig. 2. The rear wall in Fi
shows how the Furnace and Oven Room is separa
from the Metallurgical Section.

G. 7 illustrates the Meter Repair and Sensitive surements Rooms which are also closed off from emainder of the Laboratory. This area is ventilated ich a manner as to minimize the effect of dust on operations that are performed at this location.

cal Functions of the Various Sections

able I indicates the general range of the kinds of x that can be performed by the various Sections of Laboratory. Additional functions and facilities may dded from time to time.

TABLE I

AL FUNCTIONS OF THE VARIOUS SECTIONS OF THE LABORATORY

MICAL

plication and performance tests on organic and inorganic inishes
posure tests on organic and inorganic finishes
ocess control for Manufacturing Divisions
ocess development—organic and inorganic finishes
ectrographic analysis (qualitative and quantitative)
t analysis (gravimetric, electrometric, colorimetric, and itrametric

CTRICAL

lectric investigations
ctronic design and construction
ux and equipotential plotting
gh-current a-c investigations
gh-current d-c investigations
trument maintenance and calibration
gnetic measurements
chanical investigations (utilizing electrical means)
dium-current investigations
cision standards and measurements

ULATION

istance in the proper choice of insulating materials, and in onnection with field and manufacturing problems
istance on manufacturing processes
ntrol of incoming insulating materials
velopment of new materials and processes
lization of new materials and processes developed elsewhere

ALLURGICAL

velopment of new metal applications and evaluating metals or specific usages
velopment and control of heat-treating processes
scellaneous procedures (casting, annealing, hardening, solution-treating, stress-annealing, fatigue, examination of materials for structure or defects, etc.)
ysical testing (compression, tension, ductility, hardness, mpact, etc.)

DING

ed welding processes (brazing, soldering, flame-cutting, netallizing)
nsultation with, and assistance to, Engineering and Manuacturing in connection with various phases of welding and llied processes and equipment
npressure (fusion) welding processes—metallic-arc, carbonrc, and atomic arc; gas welding; and inert-gas-shielded arcvelding
ssure (resistance) welding processes (butt, flash, seam, spot, nd projection welding)

nization and Personnel

ne organization of the Switchgear Divisions Labory into its five Sections, as previously mentioned, ws the pattern of organization of other Company oratories. Each Section has its own Section Head is in charge of a group of engineers, laboratory

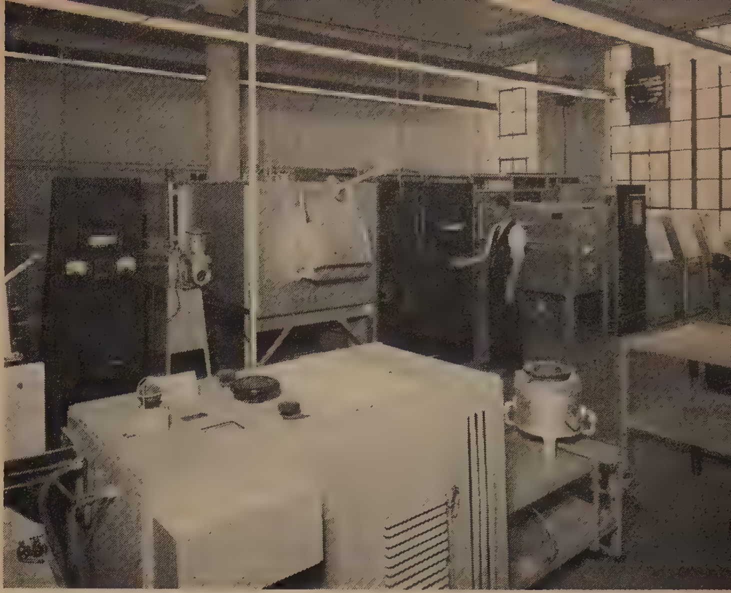


Fig. 5. Interior of furnace and oven room shared jointly by Insulation and Metallurgical Sections. (Illustration shows Metallurgical portion only.) Room exhausted directly to outside of building

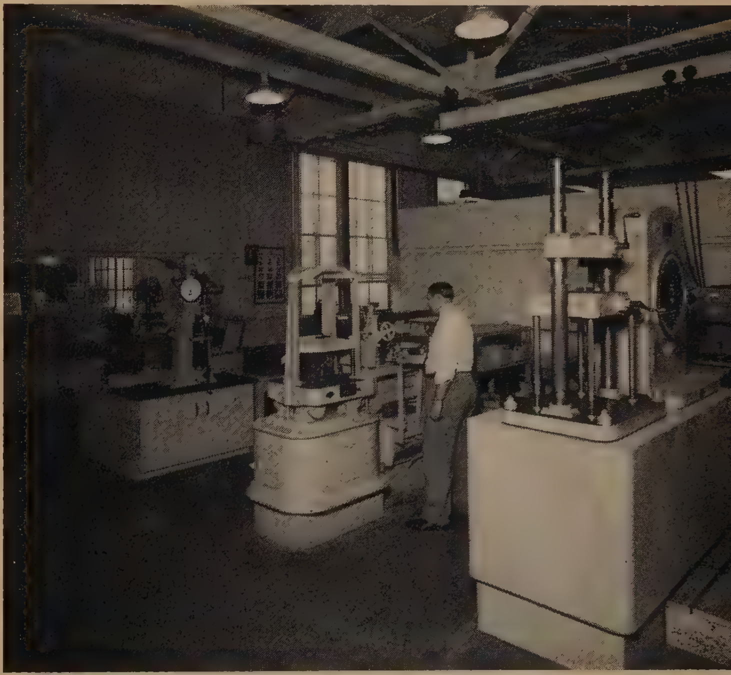


Fig. 6. Physical testing area of Metallurgical Section. Rear wall forms one side of room shown in Fig. 5.

Fig. 7. Meter repair and calibration room. Sensitive measurements performed in room at right. Entire area enclosed and separated from other parts of Laboratory. Benches in foreground used in the process of calibration against secondary standard instruments

assistants, clerical and other personnel, as well as engineers or other technical personnel in training.

The kind of an organization just described has demonstrated its worth over many years of operation. Occasionally, some problem is presented which does not fall directly into one of these divisions, or which may require the co-operation of two or more Sections. An example of the latter problem is the study of contact materials in various liquid dielectric media. Such a study required the participation, in varying degrees, of all the Sections.

A laboratory is constantly in search of high-calibre personnel. These may be found by direct contact or by observation of the performance of individuals on various training programs. The latter method is of mutual advantage to the employee and to the Company; the trainee can observe the kind of work or conditions where he is temporarily engaged, and the particular laboratory has the opportunity of interesting or selecting individuals whose performance on a specific assignment indicates that they have special aptitudes or ability for certain kinds of work.

The Switchgear Divisions Laboratory actively participates on various training programs, consisting of a number of assignments, each being usually of three-months' duration. The programs are directed toward the further training of:

Chemists and Chemical Engineers
Electrical Engineers
Mechanical Engineers
Metallurgical Engineers
Physicists
Engineers on Advanced Engineering Training Programs

In addition, the Laboratory takes an active part in training and qualifying factory personnel for such operations as welding, soldering, brazing, painting, and electroplating. The final object of this particular activity is to insure an improved and uniform product.

Planning and Co-ordination of Various Developmental Activities

Most of the major developmental activities of the Laboratory are closely co-ordinated with the Switchgear Divisions' standing committees consisting essentially of representatives from the various engineering, manufacturing, and commercial groups. The direct tie is made by means of a subcommittee, on which the Laboratory is represented. In this manner, the Laboratory's major objectives are determined by the trends of the switchgear business.

Beyond the local scene, the Laboratory maintains contacts—through numerous Committee assignments or through individual liaison—with the Research Laboratory, the General Engineering Laboratory, and other Company Laboratories. Full advantage is taken thereby of the great wealth of scientific developments which emerge from all other General Electric Laboratories. This pooling of "know-how" reduces expense and du-

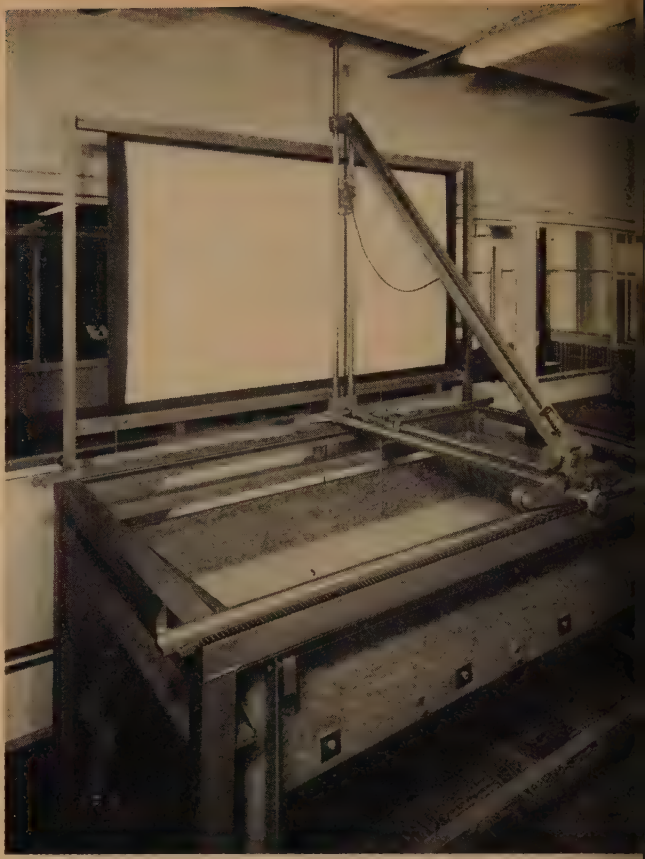


Fig. 8. Electrolytic flux-plotting unit. Models placed in adjustable slopi
bottom tank for two-dimensional plots or in deep tank (not shown) for thr
dimensional investigations. Record is made on readily removable chart sho
in background

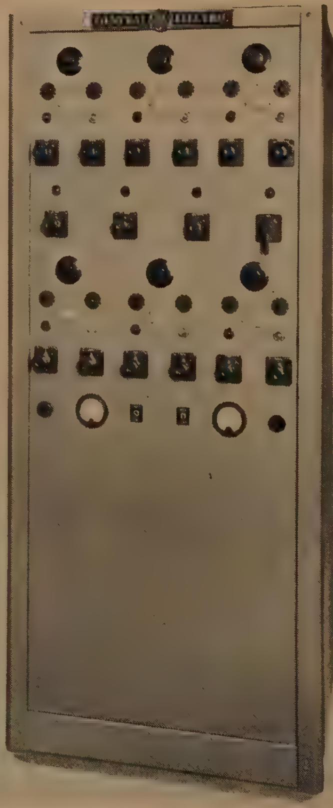


Fig. 9. Field instrum
tation equipment used d
ing power circuit-break
tests in which 12,000,0
kva was interrupted. U
contains six operating ch
nels or functions that p
vide accurate control as
timing and phase angle

ion of effort, and also hastens the termination of becific project.

ose and frequent contact is made with numerous ors supplying new or improved materials. The ratory is continually working on the testing and ation of these products.

ct Improvement

ne of the major developments undertaken by the ratory leading to product improvements, either or in the future, are summarized here. A majority ese have been undertaken since the Laboratory leted its program of expansion and modernization.

mproved paints and procedures (indoor and out- or) resulting in more durable finishes, better ap- cation techniques, faster hardening primers, and proved solvent and oil resistance.

Heavy, dense silver-plating, resulting in a superior oduct as to hardness and wear. In one circuit- eaker application, the contact-wear life was in- ased 8-fold. Its impact resistance was a valuable in the development of a line of new power circuit eakers.

Arc-phenomena investigation, leading to improved errupter performance.

Characteristics of various contact materials used switchgear.

Electrolytic flux plots of field distribution—cur- t, magnetic, dielectric, etc. The results obtained from the unit shown in FIG. 8 have been of valuable assistance in the design of various kinds of apparatus, in that a considerable amount of information can be obtained from models, which can be readily modified. Close verification has been established between the results obtained on models and the final product.

Field instrumentation equipment, as illustrated in FIG. 9, and used in recent field tests on an impulse power circuit breaker, at Grand Coulee Dam. In addition to the inclusion of a unique design for recording pressure and contact-parting-point at full line potential, the accurate control of the circuit breaker made possible by this unit aided in establishing a new industry-wide interruption record of 12,000,000 kva.

Arc quencher materials—investigation and evaluation.

Investigation of liquid dielectric for interrupters.

Investigation of laminated, molded, and cast insulation—stability and arc resistance.

Development and improvement of metallic materials, particularly lighter and stronger alloys, which are essential for the reduction in the operating time of circuit breakers.

Evaluation and improvement of bearing materials as used in various types of operating mechanisms.

Improvement in the surfacing of cams, rollers, and latches as used in various operating mechanisms.

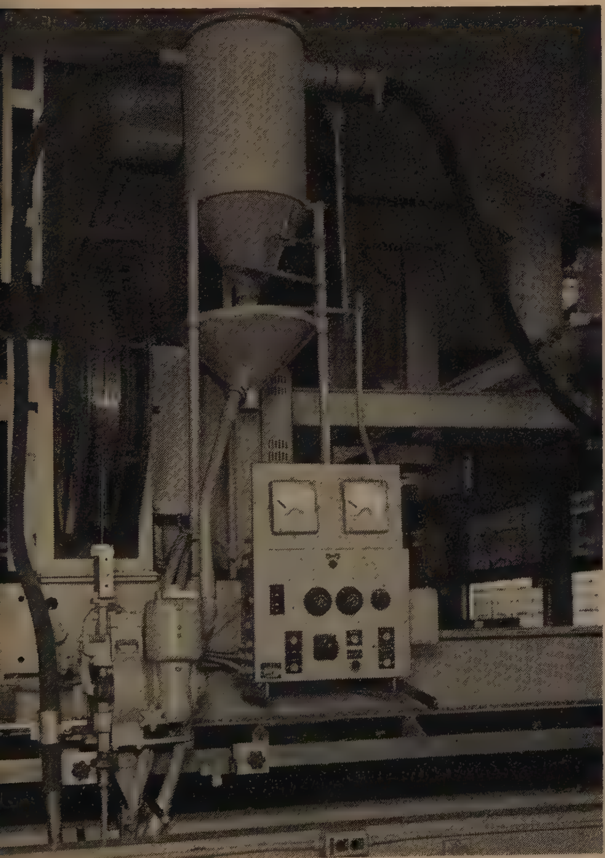
Evaluation of various bronzes when subject to corrosion under conditions of stress, as found in fittings, connectors, and other hardware.

Resistance-brazing of taps of relay coils, thereby eliminating soldered joints.

High-speed automatic submerged arc welding of air reservoirs and tanks for power circuit breakers, etc., utilizing the unit shown in FIG. 10. This process results in improved appearance and reduction in cost.

Welding of aluminum enclosures of isolated-phase bus runs, resulting in improved appearance and reduction in the number of gasketed joints.

High-speed automatic submerged arc welder for seam-welding tanks 6 in. diam. Illustration shows details of automatic feeding of wire and head moves to the right, together with vacuum unit for retrieving flux



Checking of Raw Materials and Manufacturing Processes

Through its component sections, the Switchgear Divisions Laboratory is responsible for the preparation of material and other specifications, as well as for the testing of materials and processes. This not only applies to the evaluation and checking of large and varied quantities of incoming raw materials (in lieu of certificates of analysis), but also to the daily or frequent control checks of various manufacturing processes.

As an example of the latter activity, approximately 20,000 determinations were made in one Section alone, during 1950. Another example was the improvement of one type of dielectric material; over 1,000,000 lb of this material were tested, during 1950, on a percentage basis, utilizing power-factor and other tests. This resulted in a relatively high and stable quality of the material.

A spectrograph is used extensively for replacing appreciable amounts of wet chemical analysis, particularly for metals and alloys, as well as for special and nonrepetitive problems.

New techniques are introduced from time to time. An example of this is the application of quality control to the manufacture of circuit-breaker arc chutes. By this study, in co-operation with Inspection, approximately one hundred items or manufacturing steps were readily analyzed, with the result that only a relatively small portion of these were found to be of major statistical importance. Further study of the data indicated that a check of one item, early in the manufacturing process, would result in a marked increase in the uniformity of the product. This procedure also eliminated further nonproductive machining or processing of chutes that failed to pass this test early in the manufacturing cycle.

Preparation of Manufacturing Processes

The Laboratory not only develops and evaluates various Manufacturing Processes, but also issues instructions for their application by Engineering and Manufacturing. Among the various general processes are those shown in Table II.

Associated with this activity is the calibration, maintenance, and repair of various test and production instruments and meters. These operations are performed in the area designated Meter Repair and Calibration in Fig. 1, utilizing the benches, secondary standards, and other equipment shown in Fig. 7. The accuracy of the various secondary standards and other referen units is checked periodically by the Company's Gene Engineering Laboratory, who in turn makes a frequ check with the Bureau of Standards. Thus, there is effect a regular checking procedure which insures curate measurements during manufacture, devel ment, testing, or evaluation.

TABLE II

TYPICAL MANUFACTURING PROCESSES COVERED BY LABORAT INSTRUCTIONS

Brazing
Cleaning and Slushing
Coating
Cutting
Deposition
Evacuation and Drying
Filling and Impregnating

Finishes (Organic and Inorganic
Forming (Metallic and Nonmeta
Heat Treating
Soldering
Surface Hardening
Welding

Conclusion

The foregoing analysis of the Switchgear Laborato operation should serve to indicate the numerous fu tions of an industrial laboratory, particularly one t is an essential part of a well-established enterprise. results obtained are dependent on thorough plannin judicious selection and training of personnel, adequ facilities, active participation by the Divisions serv and, finally the co-operation of other Laboratories. ultimate objectives are product improvement and sa fied users of the product.

HIGH LIGHTS AND SIDE LIGHTS

Transparent Screens for Clearer Television

Clearer television pictures, with greater contrast between light and dark areas, are foreseen with a new transparent screen for picture tubes.

The new tube is still in the developmental stage, and has not yet been offered for commercial use. However, since the presence of unseen ships and airplanes is shown on the screens of similar tubes in radar devices, it is expected that this will ultimately be another application of the new screen.

Tubes used at present are coated inside with a powder which appears white or gray, the darkest that any areas on the screen can be. When looking at one with a transparent screen, however, the viewer sees through it into the dark recesses of the tube. It is this greater degree of darkness, as opposed to the relative grayness of the usual screen, that is available for producing dark areas on the screen to contrast with light areas.

The new transparent screens, at present, show a satisfactory yellow-orange picture. It is believed that further research will make possible a true black and white picture.

In addition to yielding more contrasting images, the transparent screen eliminates another source of blurred detail. On the present powder screen, powder particles near a bright spot pick up some of its light and reflect it to the eye, thus causing a halo around the spot. There is no such powder on the transparent screen to pick up light and cause such a halo.

A simplified method of preparing durable, lasting screens by passing the chemical vapors, including the zinc and managanese, over a heated glass surface in the presence of hydrogen sulfide se to offer the greatest promise for appl tion in television sets. The screen, addition to being completely transpar shows high efficiency in converting energy of the electrons into light. Scr giving a blue picture have also obtained by this method of chem deposition.

Old Wheels Are Useful to Defense

Steel plant and foundry ventories of iron and scrap are dangerously lo present. Administrative cials in industrial plants help maintain steel produ at current record levels aid defense by canva their plants for idle, obs machinery and equipn write it off inventory and sure that dormant scrap, that shown moves qu into normal scrap-colle channels.

TABLISHING COMFORTABLE BRIGHTNESS RELATIONSHIPS

Sensation at the borderline between comfort and discomfort was used as the determining factor in a recent extensive series of investigations establishing proper relationships

Sylvester K. Guth

By SYLVESTER K. GUTH

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HE modern work world, with its requirements for
olonged critical seeing, light and lighting are of
helming importance. That this is recognized is
nced by the increasing demands for more adequate
of illumination to stimulate greater and more
ate production with less individual expended effort
mproved welfare of workers. In general, these
foot-candle levels may be obtained by one of two
methods—increasing the brightness of the existing
g equipments or increasing the number of units.
usly there are many refinements of these two
ds, but they include the essential means of
ing the desired end. However, the results ob-
have not always been without adverse comment
riticism. It has therefore been necessary to ex-
and investigate carefully certain of the aspects of
and lighting in order to determine the primary
for dissatisfaction with the resulting installa-

importance of the brightnesses and brightness
nships within the visual field have long been
ized. However, there are many factors which
whether a specific combination of brightness
ions are comfortable or uncomfortable. These
s include:

1). The brightness level to which the eyes are adapted
2). The brightness of a source or luminous area
3). The visual size of the source
4). The position of the source in the visual field
5). The number of sources in the visual field
6). The configuration of the sources
7). The criticalness of the visual tasks being performed.

implicity, the first four factors are considered
Nevertheless, the last three have important
ying influences upon the basic factors.

on

e comfort and discomfort are sensations, their
sal can be made only by those who experience
ensations. Thus, it is necessary to develop a sub-
technique which will be reliable and consistent.
ermore, it is desirable to use a criterion that is
ngful from a practical viewpoint.

Glare is the obvious and offensive result of improper brightness relationships within a visual environment, and is recognized as such. It not only produces visual discomfort but often reduces ability to see. Exposure to lesser brightnesses can be, and often is, just as effective in producing decreased ease of seeing, even though there may be no apparent reduction in visibility. Therefore, the appraisal of brightnesses in the visual field should preferably be at some level of sensation below that which is obviously undesirable.

Different individuals may vary considerably in their appraisals of what constitutes a comfortable brightness situation, but definite trends can be established. Furthermore, while it is possible for two or three observers to agree upon a series of definitions of various degrees of comfort and discomfort, any particular one would be a matter of considerable debate among a large group of individuals. Experience has indicated that a threshold, or borderline, criterion is most satisfactory. The one which appeared to fulfill these primary requisites and was adopted for an extensive series of investigations was the sensation at the *borderline between comfort and discomfort* and is termed the BCD sensation. This sensation is considered appropriate for the visual situation that involves casual, or noncritical, seeing, since with these conditions the observer is able to devote his entire attention to the evaluation of brightness.

Experimental Environment

The attainment of as complete control as possible of all the environmental conditions is an important consideration of any subjective type of investigation. Unless this is accomplished, extraneous factors may exert undue influence upon the observer, whose appraisal may be of these factors rather than of the variables being studied. Considerable care was therefore exercised in establishing an experimental environment and in developing a technique. Since these are adequately described elsewhere,(1)(2) only a brief summary is presented here.

The experimental environment used in these investigations involved a series of limited luminous areas which could be superimposed upon an extended visual field of uniform brightness. For most of the phases of this series of investigations these conditions were ob-

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nbered references are listed at the end of the article.

tained in an 80-in. photometric sphere, one-third of which was cut away, as is illustrated in Fig. 1. The observer's head was so positioned in a headrest as to locate the eyes at the center of the sphere, which occupied the entire unrestricted visual field. A lamp located immediately above the head of the observer provided the uniform brightness of the visual field. A small shield immediately under the lamp eliminated any sensation of heat or brightness from above.

Light sources mounted behind circular openings in the surface of the sphere provided the sources of brightness, which the observers were required to adjust so that they induced the sensation at the borderline between comfort and discomfort. By using appropriate filters in front of the light sources, it was possible to obtain apparent constancy of color of the sources for a relatively large change in voltage. Thus, by the proper combination of lamp and color-correcting filter, a reasonably constant spectral quality was maintained over the range of brightnesses from zero to about 30,000 footlamberts. This minimized the possibility of the color of the source influencing the judgment of the observers. Those sources which were not used during any particular part of the investigation were adjusted to equal the field brightness, and became indistinguishable from it.

Technique

The technique used for appraising the brightnesses of the sources was similar to that originally developed by Luckiesh and Holladay,(3) but was modified in accordance with later experience and knowledge. The observer was required to evaluate the initial sensation of brightness when a source was momentarily exposed to view amid the surrounding field of uniform brightness. An exploratory investigation of momentary and prolonged exposures indicated that both gave the same results for the sensation at the borderline between comfort and discomfort. This has since been established more definitely.(2) However, the observers expressed a feeling of greater confidence in their ability to arrive at the desired appraisal with the momentary exposure of the source, which was decided upon as the technique to be used. This condition approximated that of a worker looking up from the adaptation brightness of his work area, such as a desk, toward a source of higher brightness and evaluating the sensation received during the initial period that the source was viewed.

The short exposures permitted maintenance of the adaptation-brightness level as close to that of the surrounding field as possible. However, the exposure time was sufficiently long for the observer to receive and to experience the full building-up of the sensation. Considerable experimentation guided in the standardization of one-second exposures separated by one-second intervals during which the observers were exposed only to the field brightness. A ten-second cycle was devised during which the sources were presented for a subjective evaluation three times and the remaining short period was allowed for the subject to alter the brightness of the test source.

In considering controlled conditions, it is also ne sary to minimize the influence of the experimenter u the subjects. After adequate explanation of the p cedure, the subject was left alone to arrive at his c clusion at each step in the investigation. The handl of subjects is very important.

Basic Relationships

Ten observers were tested to determine the relati ships among the basic factors. They were selected as to be representative of a larger group of 50 observ who participated in an earlier investigation.(1) A group, their performance was found to be typical an "average observer." Individually, they inclu observers who were sensitive in varying degrees to a particular value of brightness.

Adaptation Brightness

The adaptation, or field, brightness is an import factor influencing the sensation induced by a source brightness. All factors except the adaptation brightn were maintained at constant values. That is, the siz the source was 0.0011 steradian* (1.48 in. diam., view at 40 in.) and was located on the line of vision. adaptation brightnesses of 1, 10, and 100 footlamb the average brightnesses at the borderline betw comfort and discomfort were found to be 302, 830, a 2325 ft-l, respectively. These values are plotted Fig. 2, and may be represented by the equation

$$B=302F^{0.44}$$

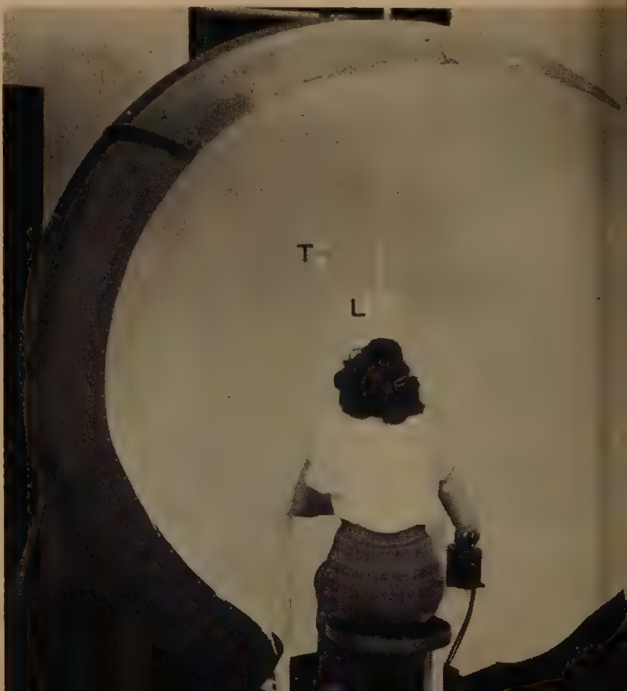

Fig. 1. The experimental environment used throughout most of the pre investigation was the illuminated white inner surface of an 80-in. spher the center of which the subject's eyes were located. This unrestricted surro ing visual field was illuminated by the lamp L, located near center of sp and concealed from the subject. Brightness of test-sources T, which are circ apertures in the spherical surface, is adjusted by the control under subj right hand. The photograph illustrates the brief period during which a source T located 20 deg above the line of vision was exposed

re B is the BCD brightness of the source and F is adaptation (field) brightness. From this relation-it can be seen that doubling the adaptation bright-F permits a 36-percent increase in the brightness the source. Conversely, if the brightness of the ce is doubled, the adaptation brightness must be eased approximately five times in order to maintain BCD sensation.

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*This unit of size is used since it combines the projected area A of the sc and the distance D from which it is viewed; it is numerically equal to A/D

of Source

ive circular sources ranging in diameter from 0.46 to n. were used for determining the effect of size upon BCD brightness. At the viewing distance of 40 in. e sources subtended solid angles from 0.0001 to 6 steradian. The physical data pertaining to the ılar sources and the average BCD brightnesses as rmined by the representative group of observers an adaptation brightness of 10 footlamberts are

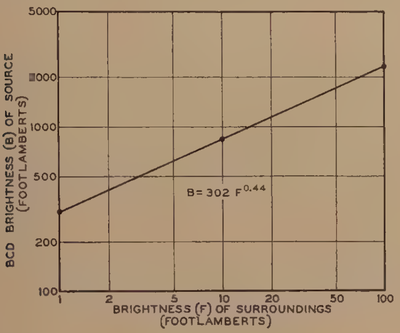


Fig. 2. Relationship between BCD brightness *B* of a source, located on the line of vision and subtending a solid angle of 0.0011 steradian, and adaptation brightness *F*

marized in Table I. The relationship between these D brightnesses B and the solid angles Q are plotted ne solid line in Fig. 3. This relationship approximates near logarithmic one for a range of Q from 0.0001 to steradian. However, the BCD brightness decreases e rapidly for larger sources, from 0.01 to 0.13 adian, than for smaller sources. The straight-line ion of the curve includes the range of sizes used by laday,(4) who also found a straight-line relationship. entire range of data may be represented by the pirical formula

$$B = 296Q^{-0.21} - 377 \qquad (2)$$

exponent of Q is in general agreement with Holla-, who found that a value of 0.25 gave a good roximation of the range he studied.

ig. 3 shows that the relationship between BCD htness and size of source is a variable one. Thus, a nge in one factor required as a result of an increase lecrease in the other factor is dependent upon the olute values of size and brightness that are involved. example, when the size Q of the source is less than steradian, doubling its brightness requires that it educed to about one-tenth of its original size. As size of the source is increased progressively above steradian, a doubling of its brightness requires gressively less reduction in size.

TABLE I

BCD BRIGHTNESS AS DETERMINED BY A REPRESENTATIVE GROUP OF OBSERVERS

Dimensions of the circular sources and the average BCD brightness in footlamberts of these sources, located on the line of vision, which produced an initial momentary sensation judged to be at the borderline between comfort and discomfort. The field brightness was 10 ft-l.

Size of source, steradians.....	0.0001	0.0011	0.0079	0.0314	0.126
Visual angle, deg	0.66	2.12	5.72	11.42	22.62
Diameter, in.....	0.46	1.48	4.0	8.0	16.0
Area, sq in......	0.167	1.72	12.6	50.3	201
BCD Brightness, ft-l...........	1660	830	447	237	82

Position of Source in Visual Field

One of the most important among the factors which have an effect upon the visual sensation induced by a source of brightness is the position of the source in the visual field. While the sources in a lighting installation often may be viewed directly, in the usual situation they are located at an appreciable angular distance from the normal line of vision. For this reason, it is necessary to have quantitative data regarding the effect that the position of the source has upon the brightness which will induce a sensation at the borderline between comfort and discomfort, or a BCD sensation.

A series of circular sources of brightness was located at various angular distances from the line of vision along the vertical, diagonal, and horizontal meridians of the sphere. The 1.48-in.-diam. sources subtended solid angles of 0.0011 steradian at the viewing distance of 40 in. Since the sources were located on the inner surface of the sphere, they were of a constant visual size and shape; the adaptation brightness was maintained at 10 ft-l.

The comparison method was used for determining the BCD brightness of the sources as they were positioned at various angular distances from the line of

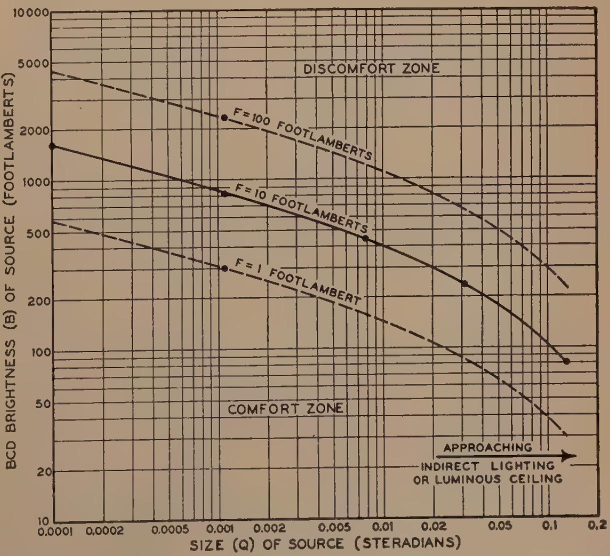


Fig. 3. The relationship between BCD brightness *B* and size *Q* of sources located on the line of vision for three adaptation brightnesses *F*

vision. A central, or comparison, source, located on the line of vision, was set at the BCD brightness of 830 ft-l determined in an earlier phase of the investigation. The eyes of the observer remained fixed on the position of the central source, and the off-axis sources were seen by averted vision. Since the comparison source was at the BCD brightness, and the off-axis sources were adjusted by the observers to produce the same visual sensation, the latter are also BCD brightnesses.

The average BCD brightnesses as determined by the representative group of ten observers are summarized in Table II. The angular displacement of the source was extended to cover the limits of the visual fields for all observers. Thus all of the observers were able to see a source located 50 deg above the line of vision, but only four were able to see the source at 60 deg. These latter data were used for extrapolating the average curve to 60 deg. Similarly, sources displaced 70 deg diagonally and 100 deg horizontally were outside the visual field for some of the subjects.

TABLE II

BCD BRIGHTNESS OF CIRCULAR SOURCES (SUBTENDING 0.0011 STERADIAN) LOCATED AT VARIOUS ANGLES (θ) FROM THE HORIZONTAL LINE OF VISION

Field brightness extending over entire visual field was 10 ft-l

Angle θ from line of vision (deg)	BCD Brightness (ft-l) Vertical	Diagonal	Horizontal
0	830	830	830
5	1165	1020	886
10	1344	1051	928
20	1764	1338	1037
30	2764	1967	1254
40	4452	2937	1463
50	7615	4500	2015
60	14000*	7658	2566
70	....	13500*	3423
80	....	....	5212
90	....	....	8396
100	....	....	15000*

*Outside of visual field for some subjects.

The manner in which the BCD brightnesses increase as a source is displaced from the line of vision is presented graphically in Fig. 4. The heavy lines representing vertical, diagonal, and horizontal displacements are smooth curves drawn through the average observed values, indicated by the circles. The thinner lines, for the intermediate meridians, have been interpolated. From these curves it is seen that a source of a given brightness is more effective in producing a specific sensation when displaced horizontally from the line of vision than when it is displaced the same angular distance vertically above the line of vision. For example, a source having a brightness of 2000 ft-l must be displaced 50 deg horizontally, but only 23 deg vertically, in order to be at the borderline between comfort and discomfort. Or stated in another way, a 2000-ft-l source displaced 50 deg horizontally and a 7600-ft-l source displaced 50 deg vertically are both BCD brightnesses fo the specific experimental conditions.

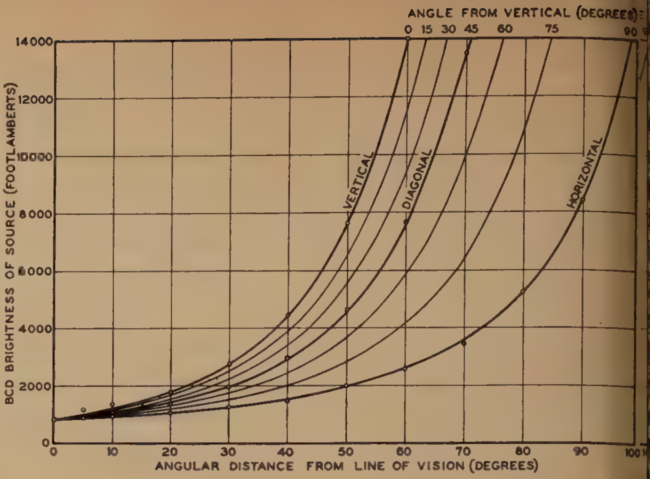


Fig. 4. Illustrating how BCD brightness increases as a circular source, subtending a solid angle of 0.0011 steradian, is displaced along various meridians from the line of vision. Heavy lines represent observed data for vertical, diagonal, and horizontal displacement. Thinner lines for intermediate meridians have been interpolated. These data were obtained when the adaptation brightness was 10 ft-l

A graphical illustration of the variation of BCD brightnesses of the circular sources located in the visual field above the horizontal is presented in Fig. 5 where the point of fixation is at zero degrees. The heavy, solid curved lines represent iso-BCD brightnesses, or lines of equal BCD brightnesses. A striking point is the similarity between the shape of the BCD curves and the curve representing the boundary of the visual field. The latter dotted curve is based upon data published by Duke-Elder, and Sheard.⁽⁵⁾ The slight dip in the curve along the vertical meridian is real, and also appears to follow the shape of the boundary of the visual field.

Combined Relationships

When the relationships between the BCD brightness B, the size of source Q, and the adaptation brightness F for the entire range of the experimental data are combined in a single expression, the following empirical formula is obtained from Equations (1) and (2):

$$B = 108F^{0.44}(Q^{-0.21} - 1.28) \quad (3)$$

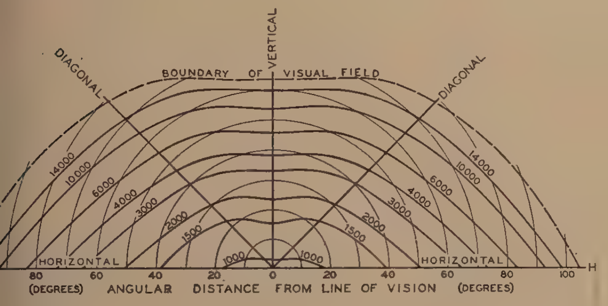
This is plotted in Fig. 3 for three values of adaptation brightness F. The solid dots indicate the points for which complete experimental data have been obtained. Dotted lines have been drawn parallel to the 10-ft-l curve for adaptation brightnesses of 1 and 100 ft-l. Sufficient data were obtained for the smallest and largest sources to check the parallel relationship which was previously found by Holladay.⁽⁴⁾

Fig. 3 and Equation (3) pertain to a source that is viewed directly by an observer. Since this is not always the case, it is desirable to incorporate in Equation (3) an additional factor which would represent the permissible increase in source brightness as the source is moved from the line of vision. This factor, which can be in terms of the relative BCD brightness of a source located anywhere in the visual field with respect to a e on the line of vision, can be obtained from Fig. 4 or Fig. 5. On these charts, however, the e is considered to be on the surface of a sphere, sitating the determination of the angle of meridian the vertical and the angular position of the source this meridian. It would be simpler to be able to the position of a source in terms of its linear cement from the eyes of the observer.

source can thus be considered to be located in a cal plane normal to the horizontal line of vision. position of the source then may be specified by a cal distance V above, and a lateral distance L at ide of, the point where the horizontal line of vision sects the vertical plane. By expressing these dis- s in terms of the distance R from the eyes to the

cal plane, the numerical ratios $\frac{V}{R}$ and $\frac{L}{R}$ become

e factors for determining a *position index* P. If osition index P is in terms of relative BCD bright- a diagram such as that shown in Fig. 6 may be to determine the BCD brightness of a source lo- anywhere in the visual field above the line of n. Figs. 5 and 6 are similar, except that linear urements are involved in the latter.



Graphical illustration of variation of BCD brightnesses of circular (subtending 0.0011 steradian) located in visual field above the hori- Point of fixation was at 0 deg, adaptation brightness 10 ft-l. Heavy solid lines represent points of equal BCD brightness. Broken curve represents ry of visual field

e position index P indicates the relative BCD tness of a source displaced from the line of vision rms of the BCD brightness of a source located on ne of vision. If the BCD brightness of a specific e located on the line of vision is B footlamberts, ermissible BCD brightness will be BP footlamberts the same source is displaced from the line of vi- Equation (3) becomes

$$B = 108PF^{0.44}(Q^{-0.21} - 1.28) \quad (4)$$

may be rewritten as

$$M = \frac{B}{PF^{0.44}(Q^{-0.21} - 1.28)} \quad (5)$$

M becomes an index of the sensation of visual rt when a source is exposed to view. When M al to 108, the combination of source-brightness B, , and position index P and the adaptation bright- are such that the initial sensation of brightness ed from the source is at the borderline between comfort and discomfort, or BCD, for the average observer. Smaller and larger values of M indicate greater comfort or discomfort, respectively.

An analysis⁽⁶⁾ of data obtained in a separate investigation with a group of 50 observers indicates that a brightness corresponding to approximately one-half the average BCD value can be expected to be comfortable for about 90 percent of those who may view the source. In Equation (4) this would mean that the value of M should be 55 instead of the average value of 108. Equation (4) may be used for determining the average BCD brightness of a source, and Equation (5) is useful for determining the numerical rating of the sensation that a source may be expected to induce.

It is emphasized that the relationships given in Equations (4) and (5) hold only for the range of the experimental data and cannot be extrapolated for larger sizes of sources without obtaining values of BCD brightness which are without meaning. For example, when the adaptation brightness is 10 ft-l and the source is located on the line of vision ($P = 1$), if Equation (5) were extended in range to a source subtending a solid angle of about 0.32 steradian, the BCD brightness would become zero, and for larger sources would be a negative quantity. Obviously this is an empirical equation of limited range. Nevertheless, the results do indicate that large expanses of luminous areas become uncomfortable even when their brightnesses are relatively low.

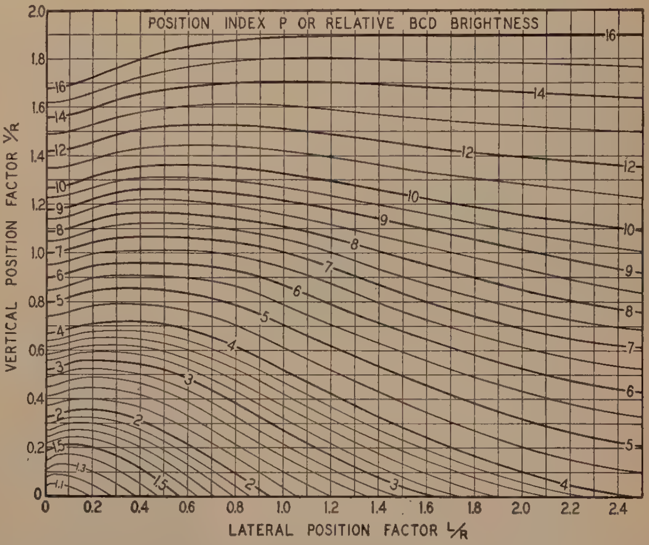


Fig. 6. Chart for determining position index P of sources located at various positions in the visual field. V and L are the vertical and lateral distances, respectively, from the line of vision; R is distance from the eye to the vertical plane normal to the line of vision in which the source is located

Conclusion

From these relationships it is possible to determine how increasing or decreasing the value of one of the factors influences the BCD sensation, and how the other factors must be varied to compensate for a change in one. If the brightness of a specific source is doubled, the sensation may be maintained at BCD by an appropriate reduction in size of source, increase in adaptation brightness, or greater displacement of the source from the line of vision. However, the actual changes required are dependent upon the absolute values of source brightness and size that are involved; for example, for a given BCD brightness of source when the size of the source is 0.001 steradian, the area of the source may be increased about 2.6 times, or to 0.0026 steradian, if the adaptation brightness is doubled. However, when the size of the source is as large as 0.1 steradian, its area may be increased by a factor of only 1.3, or 0.13 steradian, when the adaptation brightness is doubled. Similarly, changing the position of a source may be compensatory. Doubling the brightness requires a doubling of the position index *P*.

From the foregoing it is evident that when the brightnesses or areas of sources are increased to obtain higher footcandle levels, considerable care must be exercised to make the necessary compensating changes in one or all of the other factors.

The development of Equations (4) and (5) incl all the factors which can be conveniently incorpor in a single expression. The modifying factors, suc the number of sources in the visual field and the criti ness of the visual task, can more easily be introd in a general concept or method of applying the pirical relationships. These are discussed in detail where.(2)(6)

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HIGH LIGHTS AND SIDE LIGHTS

Radio Communication and Selective Dispatching

Volunteer fireman clambers out of bed in answer to fire call received on his bedside receiver

Two-way radio communication is proving its effectiveness in ever-wider use in industry and public service. As many as ten agencies can be contacted individually from a single two-way transmitter through the use of selective dispatching equipment.

An all-electronic selective dispatching method for two-way radio systems employs radically new equipment to permit "private" conversations between a dispatcher and an individual mobile unit, or a specific group of mobile units within a two-way radio system.

The newest equipment allows separation of a system into as many as ten groups. All individuals in a group hear a dispatcher's call, but when the called party responds, all other receivers in the group remain silent. Each group of receivers is activated by a separate tone signal from the dispatcher's office.

A mobile operator, under the new method, hears fewer calls not intended for his attention, reducing the number of call-backs and repeats, and lessening driver fatigue.

Volunteer firemen in an Ohio village are instantly alerted and receive instructions via an FM radio system believed to be the first of its kind in the nation.

A radio receiver, tuned to the frequency of the village's police two-way radio system, is located in each of the 27 volunteer firemen's homes. A selective dispatching device prevents the receivers in the v teers' homes from acting on police partment calls, yet permits their mediate operation in case of fire.

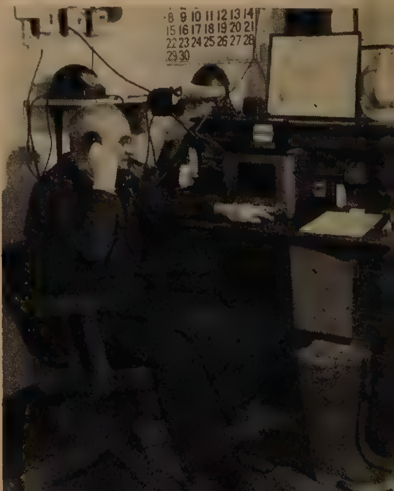
This ten-group control unit is used by a taxicab company for selective dispatching among its cars

Increased safety for underground mi long a major aim of the mining indu is expected to result from a system w provides two-way voice communic between a fixed mine station and locomotives, between locomotives op ing on a common power-supply lin fixed mine stations.

The two-way communications nique will help prevent collisions on t portation systems by aiding co-ordin of train movements, and will facil transportation and serve as an emerg communication unit in the event mine accident. Voice signals are ca via the trolley line along which the motives run. Power for the set is pro by an automobile-type storage batte

A 3-kw FM transmitter for two radio communications applications been constructed for the Kansas Police system. This new higher powe extend station transmitting range about 100 miles, depending upon ter The higher power has also been autho for Federal Government agencies.

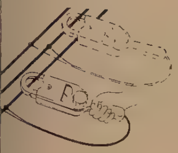
This improved carrier-current FM transmitter-receiver provides two-way communication between locomotives and/or fixed points in a mine

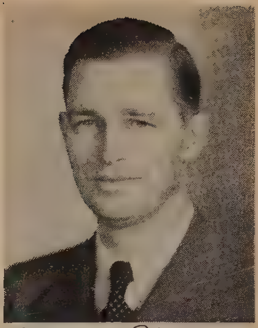


Dispatcher broadcasts an alert to all firemen and to the police cruiser

HEN YOU CAN MEASURE . . . ," WITHOUT CIRCUIT INTERRUPTION

damentals of the new instruments that round out the hook-on family measurement tools and conveniently provide the means needed lowering the cost of supplying and maintaining electric service





Arnold L. Nylander

By A. L. NYLANDER
Meter and Instrument Engineering Divisions
General Electric Company

HE most significant advancement in the portable electric instrument art during recent years has n in the field of a-c hook-on instruments. These ruments are characterized by an integral, hinged, netic hook which encircles the current-carrying luctor to supply the current component of a measnent to the indicating mechanism. It is the purpose is article to explain the operating principles of these ruments and to describe their applications.

herent in hook-on instruments are a number of ortant advantages over conventional portable suring equipment. For example:

(1). Measurements are made without any interption of service.

(2). The self-contained measurement range is unsually wide.

(3). There is maximum safety in use because ere are no circuit connections to make or break for e insertion or removal of ammeters or of current rcuits of wattmeters and power-factor meters.

(3). Less skill is required owing to the simple utine operations involved.

(5). Operation with one hand is entirely practical a result of their light weight and physical proortions.

(6). There is minimum possibility of error in use because the majority of readings are taken directly from the scale and do not involve multiplying factors.

A Family of Hook-on Instruments

Originally, the split-core current transformer was introduced to avoid the work and disruption of the circuit associated with available measuring equipment. This led to the completely self-contained hook-on ammeter which first demonstrated the convenience of the hook-on technique. One form of this instrument, which has an added independent circuit for the measurement of voltage, is illustrated in FIG. 1. With the introduction of the ammeter, the demand for this type of measurement has surpassed expectations. The wide use for measuring currents, together with the advantages of the hook-on technique, focused attention on extending this method to other measurements. As a result, contributions(1)(2) to the art in the past year and a half have made available two new hook-on instruments. These cover the measurement of watts, vars, and power factor in a significantly less complex and less time-consuming manner than has previously been possible. The instruments are illustrated in FIGS. 2 and 3.

The physical resemblance of all three instruments is obvious from the illustrations. Each has a hinged hook which is self-closing by toggle-spring action when

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Numbered references appear at end of this article.

ig. 1. Hook-on volt-ammeter

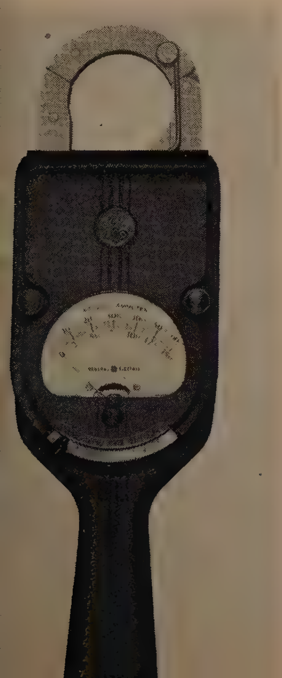


Fig. 2. Hook-on wattmeter

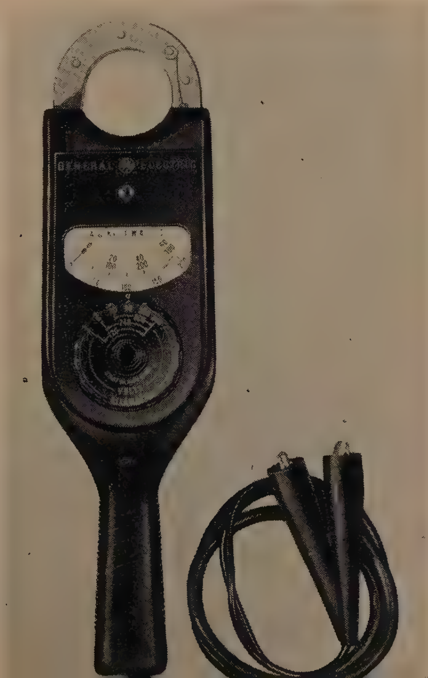
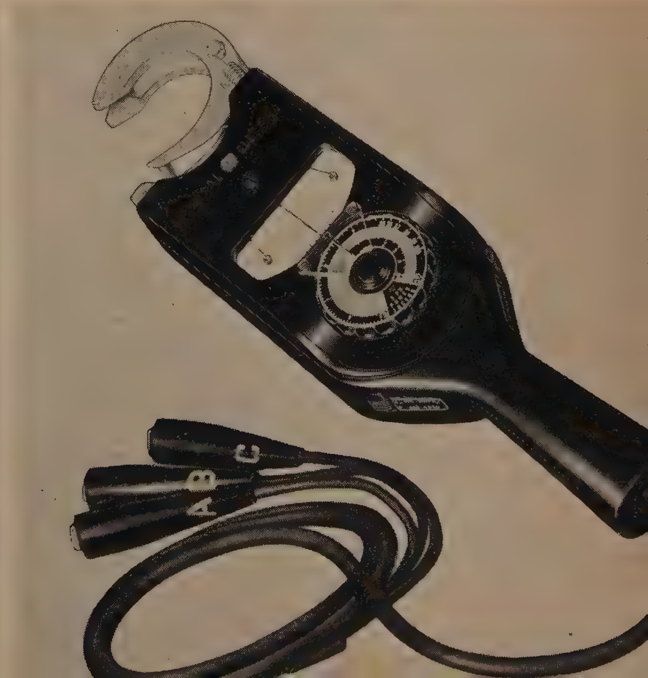


Fig. 3. Hook-on power-factor meter



pushed lightly against a conductor. They weigh only about 4 lb each and are approximately 14 in. long by 4½ in. wide by 2½ in. deep. Their sturdy one-piece molded housing and handle has been designed with particular emphasis on safety for the user. Not only does it provide insulation from the hook but also, because the handle is located well back, the hand can be kept at a safe distance from live parts of the equipment being measured. Range switching is accomplished by a simple thumb operation. Potential leads on the wattmeter and power-factor meter are constructed of high-insulation-strength rubber-jacketed rubber-covered cable and, although easily replaceable, are built into the instrument for user's convenience.

Hook-on Volt-ammeter Operation

The ammeter consists of a split-core current transformer and an indicating instrument combined into a self-contained unit. As such, the transformer must maintain a constant ratio of hook current to secondary-coil current, or output current to the indicating instrument, for each current range. The current to the indicating instrument is then directly proportional to the current being measured.

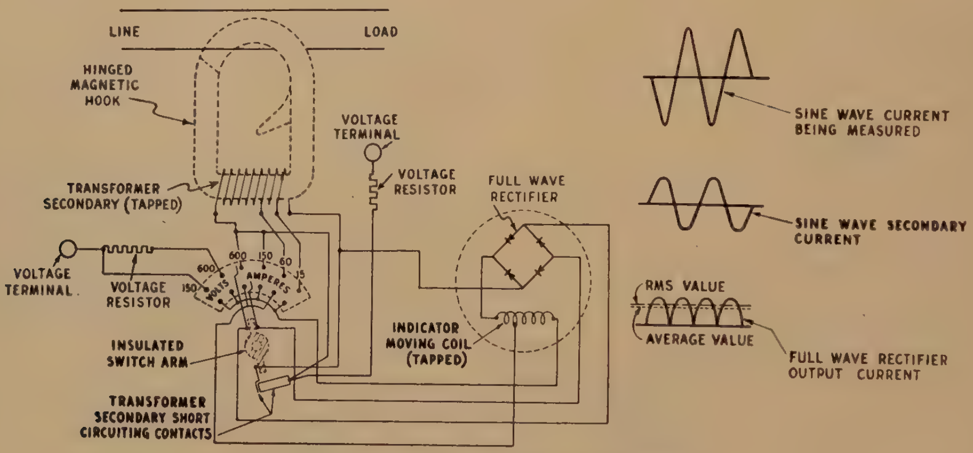

LINE
LOAD
HINGED MAGNETIC HOOK
VOLTAGE TERMINAL
VOLTAGE RESISTOR
TRANSFORMER SECONDARY (TAPPED)
FULL WAVE RECTIFIER
600
150
60
15
600
150
VOLTS
AMPERES
VOLTAGE TERMINAL
VOLTAGE RESISTOR
INSULATED SWITCH ARM
INDICATOR MOVING COIL (TAPPED)
TRANSFORMER SECONDARY SHORT CIRCUITING CONTACTS
SINE WAVE CURRENT BEING MEASURED
SINE WAVE SECONDARY CURRENT
RMS VALUE
AVERAGE VALUE
FULL WAVE RECTIFIER OUTPUT CURRENT

Fig. 4. Schematic diagram of hook-on ammeter

Of the several possibilities for the indicating instrument, the arrangement shown in Fig. 4 provides the best accuracy and most uniform scale distribution. It consists of a full-wave copper-oxide rectifier whose d-c output actuates a spring-controlled D'Arsonval instrument. Such an instrument has its moving coil in a uniform permanent-magnet field and develops a deflection torque which is directly proportional to the current through the coil. The coil therefore responds to the average value of the current. However, in a-c measurements the root-mean-square value of current and voltage is most used because these combine directly to provide watts, or power. For this reason, the volt-ammeter scale is calibrated in sine-wave root-mean-square values; it is subject to error in direct proportion to the form factor when used on other than sine waves.

The complete circuit, shown schematically in Fig. 4, results in an instrument whose indication is linear with the current being measured. Instrument deflection related to this current according to Equation (1) a single turn of the conductor through the hook.

$$D = \frac{4\sqrt{2}\,\delta\,BRL\,N_c}{981\,\pi\,KN_T}\,I$$

where

D = radians deflection

δ = rectifier efficiency expressed as a decimal

B = permanent-magnet field-flux density in gaus

R = radius of moving coil in centimeters

L = Total active length per turn of moving coil centimeters

N_c = moving-coil turns

K = control spring constant in gram-mm per radi

N_T = transformer secondary turns

I = current in rms amperes being measured.

This linear scale allows the addition of voltage c cuits which, being fixed resistances, are also linear a follow the same scale distribution. Fig. 4 shows that t different current ranges are obtained by taps on t transformer coil in conjunction with a tapped-instr ment moving coil, and with the voltage ranges resistance multipliers. A double-pole six-way swit serves as a range selector.

The Magnetic Circuit

The hook structure is designed to keep size a weight at a minimum and, at the same time, maintai the transformer ratio sufficiently constant on all range This requires the mutual flux in the hook to be directl proportional to the current in the conductor through t hook over the unusually wide current range of t instrument. It is obtained by using several materia of different characteristics in the hook to extend its line range beyond that obtainable with any single materia The use of low-reluctance dovetail joints for attachin the hinged portion to the magnetic structure minimiz the effect of the magnetic-circuit discontinuities instrument accuracy. These joints also reduce the effe of imperfect closure, such as might result from di under operating conditions, and assure good repea ability of readings.

surements

o make a current measurement, the hook is manual- apped open, then placed around the conductor and ped closed by the toggle-spring action with a push ne handle against the conductor. A range is selected he six-position thumb-operated switch to get the ing well up on the scale. To release the conductor, hook is snapped open by pulling on the handle nst the conductor.

here wiring is concealed, connections are generally e at accessible points, such as switch or terminal es. Currents can also be measured on high-voltage iits by the use of a "hot stick" or long insulating dle, which allows the user to stay at a safe distance n the circuit.

o measure voltage, the voltage leads are attached he instrument and clipped across the lines under surement. The range is selected as before and the ling taken. The instrument may be simultaneously nected for current and voltage and either read by erly switching to current or voltage.

lications

he hook-on volt-ammeter measures alternating cur- s and voltages with an over-all accuracy of 3 percent ill scale. This instrument, which has been available more than a decade, has given excellent service variety of applications. It is used to measure load ents and line voltages on motors, distribution lines, ns, transformers, and other electrical equipment, to check industrial processes.

k-on Wattmeter Operation

ower is the product of voltage, current, and the ne (power factor) of the angle between them. As rasted to current and voltage, power measurements lve circuits which will preserve phase-angle tionships.

he circuit arrangement which best provides suitable racy and wide range is shown in Fig. 5. It is a o-dynamic wattmeter whose field flux is provided the hook structure. This flux is set up by, and is portional to, the current in the conductor through hook and provides the current component of the er measurement. The voltage component is pro- d by the current in the moving coil, which is con- ed across the line through suitable current-limiting tors. As a result, the voltage component varies ctly and linearly with the line voltage.

he phase-angle relationships will be preserved if the flux is in phase with the hook current, and if the ntial current is in phase with the line voltage. le the potential current is in phase with the line age by virtue of the highly resistive circuit, the flux lags the hook current slightly because of the eresis and eddy-current losses in the magnetic e. This, however, is readily compensated by shifting potential current a similar amount with the ca- tor shown in Fig. 5.

The torque developed in the spring-controlled wattmeter moving system is given by

$$D=\frac{4\,K_2\,N_c}{981\pi\,K_1\,R}\quad VI\cos\theta^{(1)} \tag{2}$$

Where, D = radians deflection

K_2 = rms maxwells mutual flux per rms ampere applied through the hook

N_c = moving coil turns

V = applied volts

I = rms amperes applied through the hook

θ = power-factor angle

K_1 = control spring constant, gram-millimeters per radian

R = potential circuit resistance in ohms.

This shows that when the field flux in the instrument is directly proportional to the current in the conductor enclosed by the hook, the instrument deflection varies linearly with watts. Assuming the hook-structure field flux meets this condition, a number of different power ranges can be marked on the linear scale. Because the deflection D is directly proportional to the potential current or V/R, the scale range is directly proportional to potential circuit resistance so that range changing can be accomplished by potential switching alone, as shown in Fig. 5.

The Magnetic Circuit

To obtain the linear hook-current field-flux relationship without any substantial shift in phase angle over the wide current range, the design shown in Fig. 6 was developed. Here the cross section is stepped up only when going back to the center of the hook to take care of the leakage flux and maintain approximately constant flux density, thus keeping the hook weight at a minimum. Long dovetail joints are used in the hinged section to minimize the magnetic discontinuity. Air gaps are included which, incidentally, afford a con-

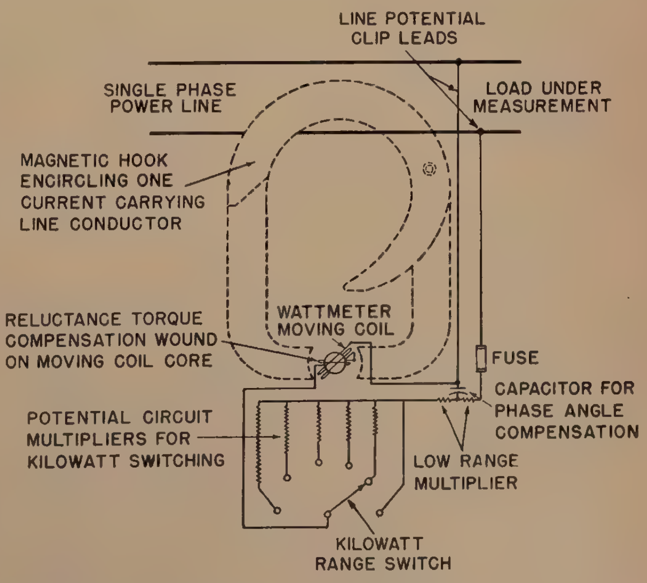

LINE POTENTIAL CLIP LEADS
SINGLE PHASE POWER LINE
LOAD UNDER MEASUREMENT
MAGNETIC HOOK ENCIRCLING ONE CURRENT CARRYING LINE CONDUCTOR
RELUCTANCE TORQUE COMPENSATION WOUND ON MOVING COIL CORE
WATTMETER MOVING COIL
FUSE
CAPACITOR FOR PHASE ANGLE COMPENSATION
POTENTIAL CIRCUIT MULTIPLIERS FOR KILOWATT SWITCHING
LOW RANGE MULTIPLIER
KILOWATT RANGE SWITCH

Fig. 5. Schematic diagram of hook-on wattmeter, showing connections for single-phase power measurement

venient place to add cupped insulators to insulate the current from the potential circuit. These gaps, together with the moving-coil air gaps, provide a high reluctance which serves to swamp out the nonlinear effects of the hook material over the extremes from low magnetization to near saturation values. The resulting hook has the required linearity to fit the linear scale on all ranges from 3 to 300 kw.

Because the ranges are switched by potential circuit resistance, the moving-coil current has widely different values from range to range. When it becomes large, it sets up an appreciable flux across the coil gaps. This flux creates a torque which tends always to move the coil toward center scale, the position of least reluctance. The torque is effectively neutralized (Fig. 4) by a magnetizing coil in series with the moving coil, but wound centrally on the core in the opposite direction.

Measurements

The resulting instrument has a high degree of flexibility to perform a variety of measurements which are listed in part:

(1). To measure single-phase power, (a) the hook is snapped around one conductor, (b) the permanently attached potential leads are clipped across the circuit, and (c) a range is selected on the thumb-actuated switch to bring the reading well up on the scale.

(2). To measure three-phase power, the connections in Fig. 7 are used. This method measures power under balanced or unbalanced conditions. Two readings must be combined in this determination.

(3). To measure vars on balanced three-phase systems, (a) snap the hook around one of the three line conductors, (b) clip the potential leads across the remaining two lines, (c) select the range to get the reading well up on the scale, and (d) multiply the reading by $\sqrt{3}$.

(4). Balanced three-phase power can be measured directly with a single reading by using the connections in Fig. 8. Here the hook encircles two of the three line conductors, the direction of one conductor being reversed through the hook opening. This measurement is made possible by the magnetic hook which adds vectorially the encircled currents.

Still other measurements can be made, such as power in three-phase four-wire circuits; two-phase three- and four-wire circuits; and single-phase three-wire circuits; and vars in two-phase four-wire circuits. These measurements are made in the same fundamental manner as with a conventional single-phase wattmeter but with greater ease and over a much wider range. This 4-lb instrument, with only a snap of the hook and the attaching of two potential clips, performs measurements requiring about 24 lb of conventional wattmeter and transformer and 18 connections, including laborious circuit-interrupting current connections.

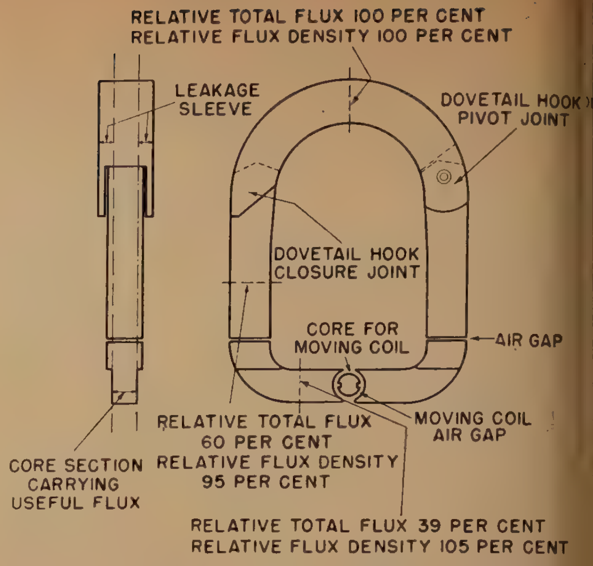

RELATIVE TOTAL FLUX 100 PER CENT
RELATIVE FLUX DENSITY 100 PER CENT
LEAKAGE SLEEVE
DOVETAIL HOOK
PIVOT JOINT
DOVETAIL HOOK CLOSURE JOINT
CORE FOR MOVING COIL
AIR GAP
RELATIVE TOTAL FLUX 60 PER CENT
RELATIVE FLUX DENSITY 95 PER CENT
MOVING COIL AIR GAP
CORE SECTION CARRYING USEFUL FLUX
RELATIVE TOTAL FLUX 39 PER CENT
RELATIVE FLUX DENSITY 105 PER CENT

Fig. 6. Hook-on magnetic structure, showing cross-sectional area proportioned to carry useful flux and leakage flux

Applications

The hook-on wattmeter has six self-contained ran of 3, 6, 20, 60, 200, and 300 kw full scale at curren from 15 to 600 amp and voltages up to 600 volts. T over-all accuracy is 5 percent of full scale. When thr phase power is measured by the two-wattmeter meth the two readings can be used to calculate power fac using the formula,

$$\text{Power Factor} = \frac{1}{\sqrt{1+3\left(\frac{R-1}{R+1}\right)^2}}$$

where R is the ratio of the smaller to the larger wa meter reading. Power factor can also be calculated fr the three-phase watts and vars readings using

$$\text{Power Factor} = \cos\left(\tan^{-1}\frac{\text{vars}}{\text{watts}}\right)$$

With this wattmeter, the watts load can be measur on motors, transformers, or other electric apparat Overloaded lines and equipment can thus be detecte Corrective measures can then be taken, such as distributing the loads between lines and between t

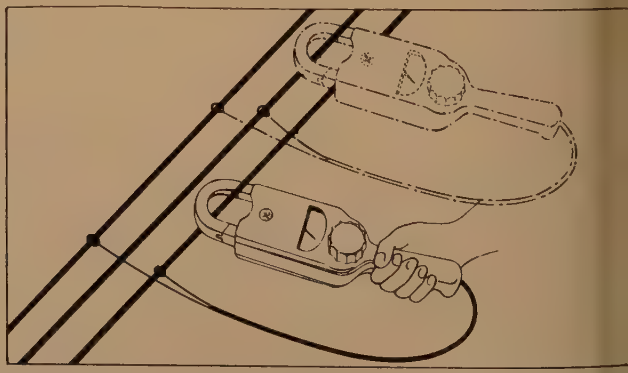
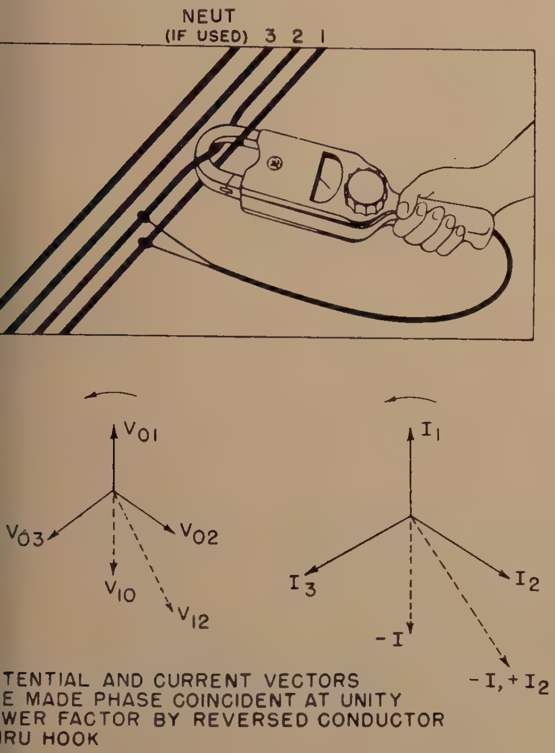


Fig. 7. Three-phase power measurement under balanced or unbalan conditions, showing how two readings are combined

of polyphase circuits, or installing the proper motors and transformers.

measures increase equipment life and reduce the of shutdowns due to circuit breakers opening or plowing. Similarly, these power measurements d to locate causes of low power factor, such as paded motors. They can also be used in industrial ses or operations as, for example, in setting up a ive machining operation to determine the um depth of cut within the power rating of the

three-phase circuit the measurement of vars he correction needed to improve power factor, s by application of capacitors, synchronous con- s, or by other load change.



Three-phase power measurement under balanced conditions made vith single-phase hook-on wattmeter

n Power-factor Meter Operation

er factor is usually measured by deflection in- nts of the crossed-coil or moving-iron type. Such nents, however, when adapted for hook-on ion have a relatively limited measurement range. rcuit of Fig. 9 overcomes this limitation with a ading galvanometer, whose field flux is set up by, in phase with, the line current through the hook, hose moving-coil current is derived from the line es acting through a cross-phase variable resistor. ntial transformer is used to provide a choice of vities. For practical purposes, its phase angle the effect of the phase angle in the magnetic The series inductance and its short-circuiting are used to determine lag or lead by introducing n phase shift in the potential circuit.

power-factor ranges and dial calibrations for a ed three-phase system are established by the

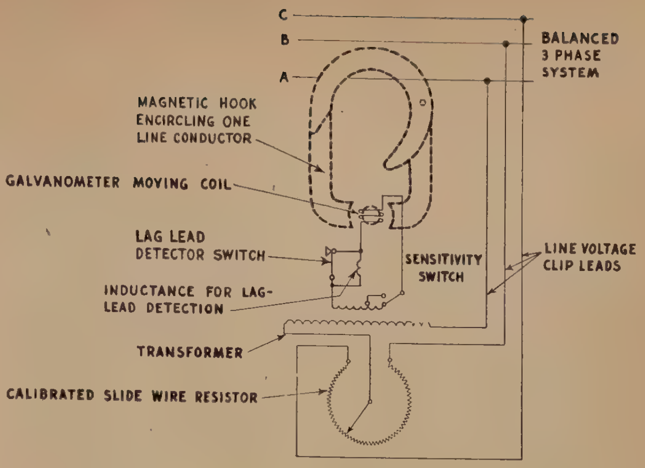


Fig. 9. Schematic diagram of hook-on power-factor meter

procedure given here. The galvanometer indicates by its zero reading a quadrature relationship between the line current and a voltage vector resulting from the line voltages operating through the highly resistive variable resistor, transformer, and moving-coil circuit shown in Fig. 9. The movable contact on the resistor shifts the phase of the moving-coil circuit voltage by adding varying amounts of line voltage V_{BC}, for instance, vectorially to voltage V_{AB}. These vector relations are shown in Fig. 10 which shows the line current and line-voltage vector relations which exist in any direct sequence-balanced three-phase circuit. Each of the three line currents has its own range of power-factor angle θ over which the galvanometer can be balanced; that is, over which the line current will be in quadrature with the potential vector within the 60-deg adjustment range of this vector. This fact gives rise to the three different power-factor scales *A*, *B*, and *C*, corresponding to whether line *A*, *B*, or *C* is being encircled by the hook. In Fig. 10 the hook encircles line *C*, and it is seen that the measurement range is 0 to 60-deg lag. The corresponding positions of the variable resistor are mechanically calibrated for this power-factor range of unity to 0.5 to provide the *C* scale. If the resistance of the slide wire varies directly with mechanical rotation, scale calibration can be

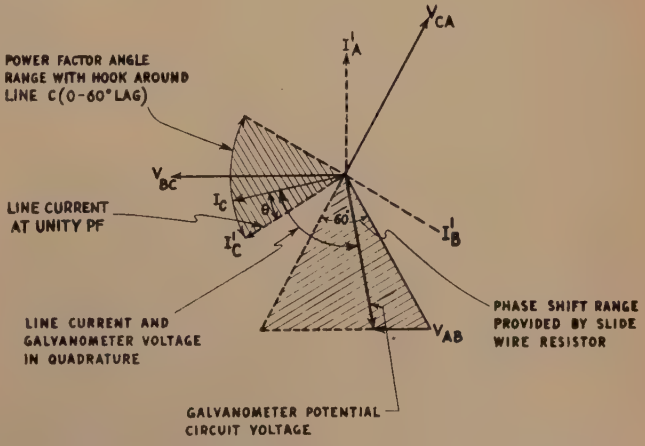


Fig. 10. Vector relations of hook-on power-factor meter with *C* line current through hook

derived simply from the trigonometry of FIG. 10. For example, for the C scale,

$$k = \frac{\sin \theta}{\sin (120^\circ - \theta)}$$

where, k = ratio of variable resistor ohms in line B to total resistor ohms (Fraction of resistor rotation)

θ = power-factor angle.

When the hook encircles line B, the measurement range is 0 to 60-deg lead to provide a unity to 0.5 lead B scale. When the hook encircles line A, the range is 60-deg to 90-deg lead and 60-deg to 90-deg lag, resulting in a 0.5 to 0 lead and 0 to 0.5 lag A scale. Lead scales are colored red and lag scales black for direct phase sequence and vice versa for reverse sequence. These three scales, each extending over 300 deg, cover all power factors zero to unity, lead and lag, and provide good legibility with their total scale length of 13½ in.

The Galvanometer

The lower limit of 1500 va at which accurate measurements can be made is established by the sensitivity of the spring-controlled galvanometer. This sensitivity is derived from fundamental electrodynamic instrument principles and the circuit-vector relations as

$$S = \frac{K_3 \sqrt{1-k+k^2}}{\sin \theta \; [R_{eq} + (k-k^2) \; R_p]} \qquad (3)$$

where, S = galvanometer deflection in radians per unit power factor per volt-ampere

K_3 = effective galvanometer constant including transformer ratio

R_{eq} = ohms equivalent impedance of transformer with galvanometer burden

R_p = total variable resistor ohms.

Measurements

Power Factor. To measure any balanced three-phase power factor, clip the leads A, B, and C at random to the three lines and snap the hook around one line as in FIG. 11. Return the galvanometer pointer to zero by turning the large power-factor dial. If the galvanometer does not return to zero, snap the hook around whichever of the remaining two lines will return it to zero. Read the value of power factor under the stationary index line, using the scale corresponding to the clip lead marking on the line encircled by the hook.

Lag–Lead Determination. To determine whether current is lagging or leading, depress the red push button, and then rebalance the galvanometer by turning the large dial. Lag or lead is indicated by an increase or decrease respectively in the power-factor reading.

Phase Sequence. The phase sequence of the circuit being measured is established by noting the color of the scale used and whether the current is lagging or leading. For instance, the clips A, B, and C are connected in direct sequence if

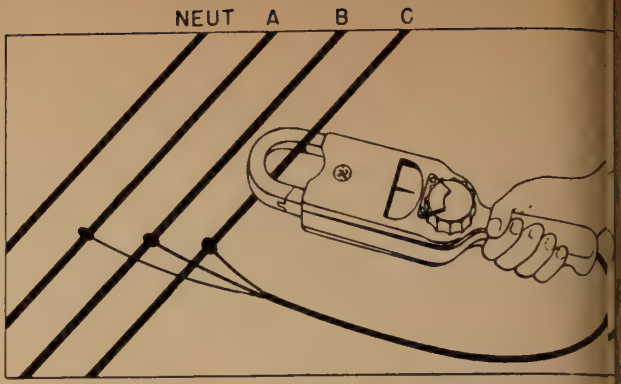


Fig. 11. Three-phase power-factor measurement under balanced condi

(1). a power factor is measured on a black scale the current is lagging, or

(2). a power factor is measured on a red scale the current is leading.

The clips A, B, and C are connected in reve sequence if

(1). a power factor is measured on a red scale the current is lagging, or

(2). a power factor is measured on a black sc and the current is leading.

Thus, with this instrument, the connections operation are so simple as to require less user skill knowledge than otherwise required for such measu ments. This 4-lb instrument covers the same range power factor, voltage, and current as about 24 lb conventional power-factor meter and instrument tra former. It does so without any time-consuming circu interrupting current connections.

Applications

The power-factor meter measures any value balanced three-phase power factor from 0 to unity, or lead, at currents from 15 to 600 amp and volta from 100 to 600 line volts. It has an over-all accura within 0.05 power factor. With this meter, individu load power factors can be checked and correct action taken on low-power-factor loads to reduce l losses and release the line capacity for product power. Checks on system power factors are of va where power users are billed on an energy consumpt and power-factor basis.

Special Applications

These three hook-on instruments provide all measurements normally required to completely est lish power-circuit conditions. In addition, their fle bility allows still other measurements such as h described:

(1). Their use can be extended to include sma apparatus and electric appliances by pass more than one turn of the conductor throu the hook. This conveniently extends the c rent range of all three instruments to lo values of current in direct proportion to the number of turns used. The power-factor meter reading remains direct, whereas the ammeter and wattmeter readings must be divided by the number of turns used.

From readings of volts, amperes, and watts, power factor can be calculated as the ratio of watts to volt-amperes.

From reading of volts, amperes, and vars, three-phase power factor can be determined.

$$\text{ower factor} = \cos\left(\sin^{-1}\frac{\text{vars}}{\text{volts} \times \text{amperes}}\right)$$

Current and voltage ranges can be extended upward by the use of conventional instrument transformers.

The magnetic hook adds currents vectorially so as to be useful in special instances; for example, to find the phase angle between two currents, use the ammeter to measure the currents I_1 and I_2 individually, then pass both currents simultaneously through the hook to get the vector sum or resultant current I_r.

Then, by the law of cosines,

$$\text{Phase Angle} = 2\left(\cos^{-1}\frac{I_r^2 + I_2^2 - I_1^2}{2I_rI_2}\right)$$

Conclusion

With the contribution of two new hook-on instruments to measure watts, vars, and power factor, it is now possible to establish conditions in lines and equipment safely and quickly, with little effort and skill, and without any service interruption. Together with the extensively used ammeter, these two new instruments round out a family of measurement tools which conveniently supply the facts needed to lower the cost of supplying and maintaining electric service by obtaining the best utilization of electrical energy.

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GHTS AND SIDE LIGHTS

Gauss Meter as a Solution to Production Problems

Gauss meter here checks the magnet in a road sweeper that is used to remove nails and other bits of iron from highways

ertain types of separation work, an -use measuring instrument is needed termining the strength of a magnet ss. The exact strength of the magnet n some types of separation equip- must be controlled to within small nces, especially where the strength magnet varies with each separate rough. The correct control was ally acquired through the use of uss meter.

instrument gives a true gauss g, regardless of its relation to lines of force or its distance from the poles of the magnets.

Separators are widely applied in removing tramp iron from processing machinery; in preventing metallic sparks in inflammable or dusty atmospheres; and in purifying nonmagnetic substances. One type of separator removes iron particles from candy bars.

The gauss meter has proved to be the answer to one company's problem of conveniently and quickly determining the strength of horseshoe magnets.

Most Powerful American Ship's Service Electric Installation

Six turbine-generator auxiliary sets, comprising the strongest electric power installation ever designed for an American merchant vessel, have been supplied for the superliner S.S. *United States*, which was launched on June 23 at Newport News (Va.) A 51,000-gross-ton express liner presently under construction for the United States Lines, the new flagship was designed to contain all of the technological advancements made in shipbuilding during the past decade.

This superliner's auxiliary generator sets are capable of supplying a power output sufficient for the needs of a full fighting division (14,500 men) in the event the ship is transformed into a troop transport. Compared to the usual marine generator installations, the new sets on the *United States* are relatively small, and were especially designed to fit the small space allowed for such equipment on this particular ship. The generator sets are also unusually quiet while in operation.

Despite space limitations, the generator auxiliary sets furnish the highest kw total of electric power ever produced aboard any American merchant ship. All equipment was designed to meet U.S. Navy specifications, with an extremely precise degree of voltage and frequency regulation. This finely regulated power output means that a steady given amount of power can be attained at all times for the proper functioning of electric ship equipment.

AN ECONOMICAL INDUSTRIAL X-RAY DETECTO

The application of cadmium sulfide crystals in suitable form to utilize their photoelectric properties and self-contained amplification, provides a versatile automatic device

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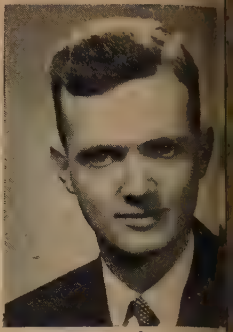

THE efficiency of a detector for x-rays is determined by two factors. The first is the absorption of the incident radiation. The second factor is the conversion of the absorbed energy into photoelectrons and the production of the optical or electrical signals by these photoelectrons.

In detectors for longer wavelengths—that is, visible or ultraviolet radiation—the absorption does not offer specific problems. However, the penetrating power of x-rays is so great that considerable thicknesses of matter are necessary in order to obtain an appreciable amount of absorption.

Amplification Mechanism

In gases the absorption of x-rays is generally very low. Even an ionization chamber or a Geiger counter filled with heavy gases like krypton or xenon must have an extended absorbing layer to obtain sufficient absorption. Fortunately, the photoelectrons released in the Geiger tube do not represent the total signal obtainable. They serve to initiate an electric breakdown in the tube and it is this breakdown surge which, limited by a suitable arrangement of the current supply, produces a large amplification of the ionization obtained by a single x-ray quantum passing through the counter.

Without such amplification mechanism the increased absorption obtained with solid detectors such as photographic plates, luminescent phosphors, or photoconductors would not offer any great advantage over the ionization chamber or Geiger counter. However, in a photographic plate, a single silver speck produced by photoelectrons in a silver bromide grain causes the whole grain to be reduced by the subsequent process of developing. It is well known that this development represents an amplification of the original latent image by a factor of 10^6!(1)

In a luminescent phosphor the amplification is small. One 50-kv x-ray quantum absorbed in a phosphor grain produces less than 2×10^3 quanta of visible light, instead of 2×10^4 quanta to be expected if this conversion into visible light (2.5 eV) would take place without losses.(2) The energy chain: x-ray quantum→photoelectron→light quantum has only 10 percent efficien The high effectiveness of the combination (phospho photomultiplier) is mainly due to the amplificat factor (10^6) of the multiplier. The chain: x-ray qu tum→photoelectron→visible quantum→photoelect →secondary electrons is rather complicated and c nected with many losses.

With the usual photoconductors, lead sulfide thallous sulfide, very small effects are obtained w x-rays. These photoconductors show a certain amplifi tion factor when used with light, but the dark curre are so high that the small changes obtainable by x-ra in the thin and weakly absorbing layers, hardly exce the noise level. The same can be stated for seleniu which has been sometimes used as a photoresistance barrier-layer cell with x-rays.

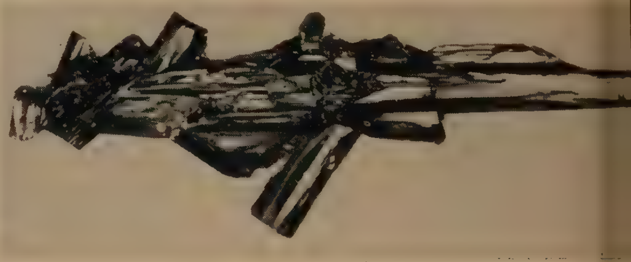

Fig. 1. Group of CdS crystals as obtained from growing furnace. The sp men shown here is about 2.3 mm long

Crystals as Photoconductors

A photoconductor which shows high dark resistan and very high amplification of the primary photocu rents is hexagonal cadmium sulfide, which can synthesized from cadmium vapor and hydrogen su fide.(3) With such crystals (Fig. 1) a ratio of the da current to the current under irradiation of $1:10^4$ c be obtained with moderate x-ray intensities. The hi dark resistance makes practical the use of crysta having many millimeters thickness, which will absor large part of the impinging x-rays (Table I).(4)

The crystals belong to the class of crystal phosph similar to zinc sulfide activated by copper or zi cadmium sulfide activated by silver. In making t CdS crystals it is not necessary to add an activat to the cadmium sulfide. The crystals generally show red luminescence under irradiation with ultra- light or with x-rays. It is therefore safe to assume the interstitial cadmium atoms act as activating rities in the same way as the copper activates zinc e.

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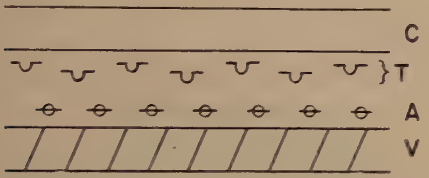
(1)Numbered references are listed at the end of the article.

order to understand the mechanism of the unusual photocurrents in these crystals, we should con- the band model of a crystal-phosphor as shown in 2. The crystal represents a large macromolecule. e unexcited state, the electrons occupy the states ne uppermost filled band, the valence band V. ted above this band there are the states of the uction band C in which electrons move freely igh the whole crystal. If the lattice is indefinitely ided and if it does not contain any impurities or ts, these two bands represent the only possible



Band scheme for CdS to demonstrate mechanism of producing photo- ts

s for the electrons of the lattice. However, in a real al with surfaces and imperfections, additional s have to be introduced. They are located between valence and conduction bands and represent the lled electron traps T. Electrons moving in the uction band can be trapped in these localized s. Furthermore, impurities in the lattice—for nce, the already mentioned cadmium atoms— sent additional states which we call activating rities A. The theory of phosphorescence has n(5) that these impurities are responsible for the sion of the radiation of the particular phosphor. can very easily lose an electron; and if an electron ns from the conduction band into the activator, orresponding energy is emitted as light.

anism of Photoconductivity

ing the energy diagram one can assume the follow- nechanism for the photoconductivity in cadmium le and similar phosphors. If a potential is applied o electrodes of the crystal, a small dark current low through it. This current is carried by the small

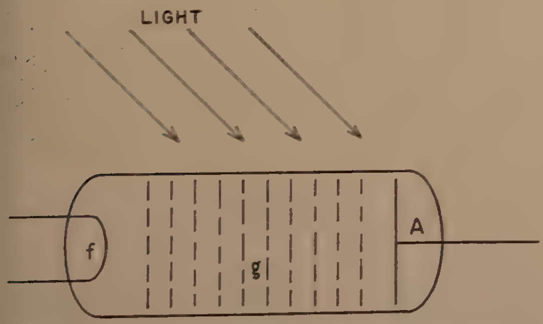


Fig. 3. Vacuum-tube analogy of CdS crystal mechanism
f: Filament *g*: Free floating grids *A*: Anode

TABLE I

X-RAY ABSORPTION IN CADMIUM SULFIDE CRYSTALS

Wavelengths	Crystal Thickness for 99% Absorption
0.13A	7.4 mm
0.20	2.16
0.31	0.66
0.40	0.36
0.45	0.25
0.47 (K edge)	1.30
0.51	1.06
0.61	0.62
0.71	0.42
0.83	0.28
0.92	0.20
1.04	0.14
2.09	0.02
3.02	0.009
3.72 (L edge)	0.028
6.14	0.008
9.86	0.002

number of electrons which are lifted up by thermal impacts from the activating impurities into the conduction band. The conductivity depends on the temperature according to the well-known law

$$\log \delta \propto \frac{1}{T}.$$

The number of electrons present at each instant in the crystal is determined by the stationary negative space charges of the electrons which are held in the trapping states. If one electron leaves the crystal at the anode, another electron enters the crystal at the cathode and the number of electrons in the crystal stays constant. When an x-ray quantum is absorbed in the crystal, a number of electrons are lifted up from the valence band into the conduction band. The empty spaces (holes) in the valence band are fast taken up by electrons of the easily ionizable activating impurities.

The activators which lost an electron thus represent positive and stationary space charges. A positive stationary space charge compensates partly the negative stationary space charge of a trapped electron; and, to restore the original charge distribution in the crystal, one additional electron will enter the crystal at the cathode. If it leaves the crystal at the anode, another electron will enter the crystal. This chain will be kept up as long as the stationary positive space charge persists. The positive space charge can be neutralized only if an electron recombines with it. It is in this way that the small recombination probability between electrons and positive-charged activators determines the length of the electron chain. For one electron raised into the conduction band 10^4 to 10^5 electrons are carried across the crystal if the field strength applied is about 500 volts per mm. Furthermore, it follows from this model that the recombination probability is proportional to the square of the number of electrons in the conduction band.

It is interesting to replace the complicated mechanism of the cadmium sulfide crystal by a simple model. FIG. 3 represents a vacuum tube with a filament f,

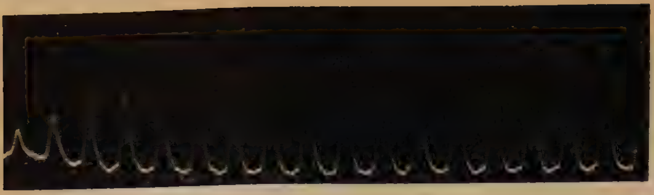


Fig. 4. Time response of a-c component of crystal current when crystal is irradiated with pulsating x-radiation

anode *A*, and a number of free floating grids *g*. If a potential is applied between the hot filament and the anode, a small current will flow. The size of this current is regulated by the distribution of negative charges on the grids. We assume now that the surface of the grids is photoelectrically sensitive. By irradiation the grids lose some electrons which drift with the field, are retrapped at another grid or reach eventually the anode. The negative space charge is reduced and the current will increase until an electron trapped on one of the grids restores the original state. In this model the creation of a positive space charge close to the cathode produces a larger increase of the current than the positive charge on a grid which is close to the anode. In the same way cadmium sufide crystals show much higher photocurrents if the impingent radiation hits the region close to the cathode.(6)

This model furthermore illustrates why all the calculations of the photocurrents in cadmium sulfide undertaken up to now have failed: It has not been possible to determine the distribution of the electrons in conduction band, traps, and activating impurities to use as a basis for a calculation of the photocurrents.

From these considerations it appears that the photocurrent depends in a complicated way on the actual distribution of the positive and negative space charges in the crystal. By thermal impact, a small number of electrons are continually lifted up from the activators as well as from the traps into the conduction band and in a like manner they fall back into the activators and into the traps. This rearrangement of the space charges is responsible for the delay in reaching a final value of current when a constant irradiation is applied or removed.

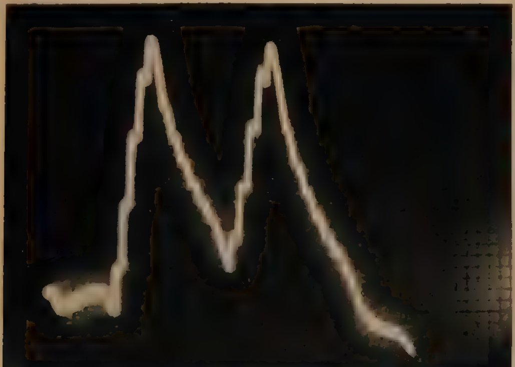


Fig. 5. Total crystal current as incident intensity is varied

Crystal Performance

An average crystal such as is used in x-ray pract will take approximately 5 seconds to reach 95 perc of its final value under typical values of x-radiati With very weak irradiations—for example, gamma r of a few mg of Ra—this process of adjusting of the el trons in the crystal can take several hours!(7)

As was previously pointed out, when the radiat ceases, the electrons in the conduction band recomb with the activators according to the familiar relat

$$\frac{dn}{dt} = -b\,n^2$$

where b is the recombination coefficient and n is t number of electrons.

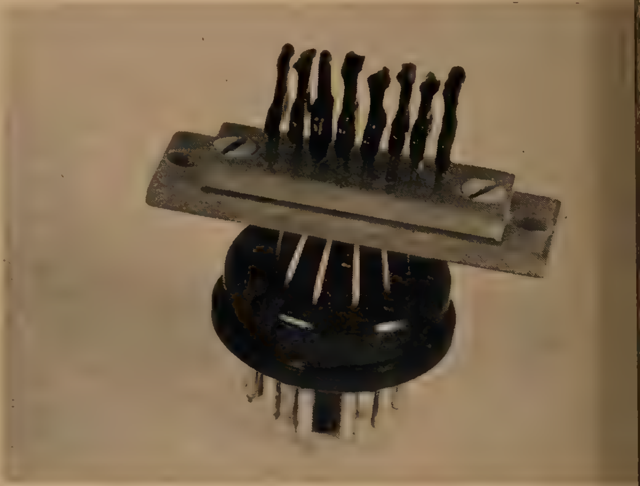
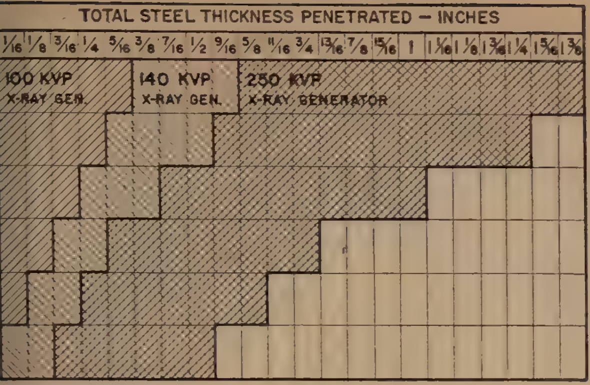


Fig. 6. Detector head consisting of eight CdS crystals arranged to give a level gaging precision of $\frac{1}{16}$ in.

This relation may be used to an advantage where t x-ray source is pulsated as in the majority of comme cially available equipment. Although the d-c compone of the photocurrent continues to increase over som time, the a-c component reaches a steady state in matter of a few cycles, as shown in Fig. 4. This observ tion(8) made it possible to adapt CdS to high-spe automatic inspection with x-rays.

For Fig. 4 an amplifier having a cutoff at 40 c was used to remove the d-c component. The x-ray ge erator produces a distinct pulse of x-radiation eve 1/60 second, as revealed by the oscillogram of t crystal current. The sum of the two components (a and d-c) of crystal current under pulsating x-radiatio is shown in Fig. 5. Here one should note that eve though the average value of the current continues increase, the modulation or the a-c component due the pulsating nature of the x-rays quickly assumes steady value.

In Fig. 5, after 5 cycles, the beam was interrupted f 7 cycles by a fast-moving object, then the beam w unblocked for 5 more cycles and then reduced agai If the total current were used, it would be extreme difficult to instrument for the changes; but, with the a component, these changes are easily observed.



. Chart for determining x-ray generator needed when applying CdS
. X-ray tube current is 5 ×10^{-3} amp

ication

e full advantage of the CdS crystal x-ray detector
t shown by its application in gaging of liquid levels
rge thick-walled vessels, where because of the
e of the liquid handled or location of the vessel,
anical or electric-contact type gages are not suit-
⁹⁾ As shown in FIG. 6, the small size of the indi-
l detectors makes it possible to arrange eight on a
line, thus giving a precision of gaging of $\pm\frac{1}{16}$-in.
use of the high absorption and natural amplifica-
of the CdS crystals, currents in the order of 100
amperes are obtained in this application. FIG. 7
s how the size of x-ray generator varies with con-
r wall thickness and diameter.

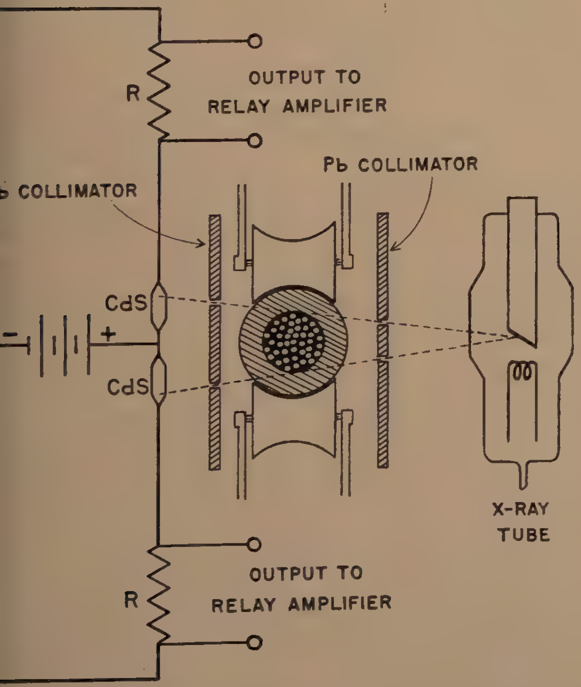
r high-speed automatic x-ray inspection of objects
ndom sequence, a special amplifier system has been
oped. The a-c component of crystal current is
fied and caused to pass through a coincidence gate
t, which serves to indicate when an object is present to be inspected. This is necessary because these inspectors use a change in x-rays transmitted to determine a faulty object. The same change greatly magnified would be presented to the amplifier output when there is no object at all in position for inspection. The gating circuit serves to pass the indication of a faulty object from the amplifier to the rejection relay circuit only if an object is in the inspecting position. This system is used for the inspection of canned and packaged goods for height of fill at rates exceeding 600 units per minute.

If it is desired to inspect a homogeneous line of material—for example, the copper core of electric cables or the powder train of blasting fuse—for continuity or position, only the high speed a-c amplifier is used.

In the inspection of the blasting fuse, the crystal is mounted in such a manner that its major axis is parallel to the line of travel of the train. This configuration is used because voids in the train are to be detected.

If concentricity of core in electrical cable is to be checked, two crystals are mounted in such a manner that the negative electrodes are just outside the limits placed on the core's position. This is illustrated in FIG. 8. Because it is not practical to rotate the cable, two such inspecting stations should be used in such a manner that the x-ray beams are normal to each other. Laboratory measurements have shown that it is possible to detect within 0.010 in. the position of the 0.500-in. conductor in a ¾-in. OD cable.

From the few applications cited, the versatility of the CdS x-ray detector is readily seen. Inasmuch as the crystals supply their own amplification, associated equipment needed in the form of x-ray generators and instrument amplifiers is greatly simplified with the result that an economical system can be devised to automatically handle problems heretofore requiring large outlays in equipment and personnel.



Arrangement of crystals when used to detect nonconcentricity of
or in plastic-insulated cable

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GROUNDING OF INDUSTRIAL SYSTEMS

A practical survey of conditions under which power is supplied gives an answer to the questions of whether and how systems and equipment should be grounded at various circuit voltages

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W. C. Bloomqu

WHETHER a power system should be grounded is not always subject to rigorous engineering analysis and economics. Often past experience is no guide because, until recent years, few plant engineers have had operating experience on both grounded and ungrounded systems. However, the trend is to grounded operation for both industrial and utility systems.

The purpose of this article is to offer practical suggestions on both power-system grounding and equipment grounding, indicating the more practical and accepted methods of system grounding for various operating voltages, and the elements that should be incorporated in the equipment-grounding system.

To avoid misunderstanding, the distinction between "system" and "equipment" grounding should be clearly understood. In this presentation they are defined as follows:

> A "grounded system" is a system of conductors in which at least one conductor or point (usually the neutral point of transformer or generator windings) is intentionally grounded, either solidly or through a current-limiting device.
>
> An "equipment ground" is the connection to the ground bus from the noncurrent-carrying metal parts of the wiring system or apparatus connected to the power system. As used in this sense, "equipment" includes all metallic parts such as conduits, raceways, armor over cable, outlet boxes, switch boxes, motor frames, enclosures of motor controllers, etc. The ground bus includes the entire metallic network connected to the station-ground electrodes.

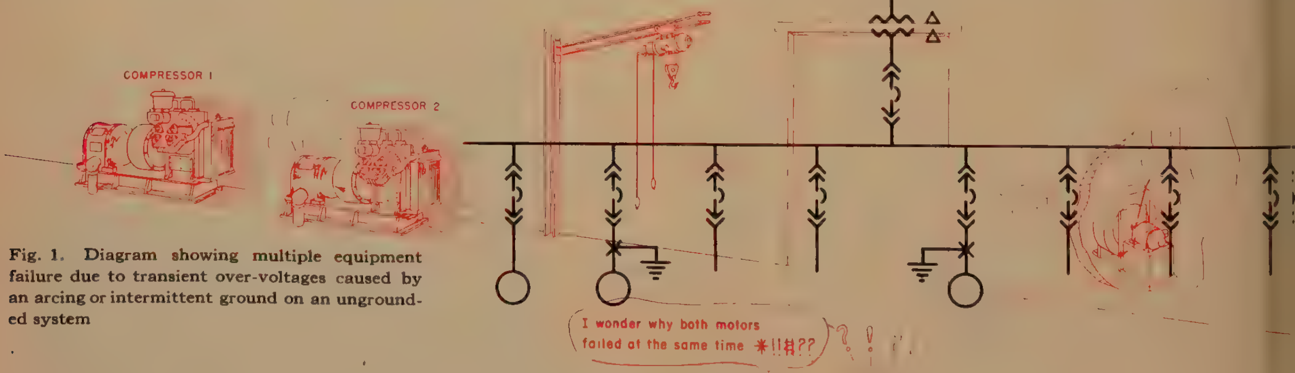

Fig. 1. Diagram showing multiple equipment failure due to transient over-voltages caused by an arcing or intermittent ground on an ungrounded system

Overvoltages on Industrial Power Systems

All power systems, regardless of voltage, are subject to some overvoltages, such as those associated with lightning and switching operations.

Of far more importance in industrial systems are overvoltages which can occur on ungrounded syste as the result of the phenomenon of "restrike." Altho restrike is generally associated with utility systems switching operations, that same mechanism is resp sible for overvoltages—several times the system volt —in industrial plants and is often evidenced by multi failures of motors, potheads, and cables as shown FIG. 1. The overvoltage is caused by *intermittent* arc to ground; for example, this may be due to vibrat causing a grounded motor winding to make intermitt contact to ground.

During recent years much has been learned about nature and causes of these overvoltages from mat matical analysis and analyzer studies correlated w service experience. Many equipment failures that w perplexing a few years ago are now understood explainable.

Grounded Versus Ungrounded System Operation

Grounded System

Perhaps the best evidence in favor of ground system operation is the actual record. To the auth knowledge not one single plant that has changed t grounded system has changed back to ungrounde system operation. Also, not one plant which initia started with a grounded system changed to ungroun operation.

Presented as a paper at the Midwest Power Conference in Chicago, Illi April 5, 1951, sponsored by the Illinois Institute of Technology.—EDITO ly, the advantages of a grounded system are:

). Greater safety

becomes especially important with proper ent grounding by virtue of the stabilized relap of service potentials to ground. Also there is bidance of overvoltage due to a conductor break- l falling on another wire where both high-voltage w-voltage conductors are carried on the same r in case of internal failure of transformer wind-

). Automatic and selective indication of ground faults

e faults can be quickly located. Experience on ltage systems shows that grounds are generally in anch feeder circuits, and selectivity of circuit n is obtained.

). Reduction of transient overvoltages

is explained in the previous section dealing vervoltages.

). Better over-all protection to equipment

is especially true for generators and motors pro- by differential-type relays. The faults usually s a winding failure to ground, so that differential with low pickup settings and fast operating time ood protection. Where such relays may not be nically justified, conventional ground relays offer rotection because their pickup can be set low and ndent of the circuit load current. On the other a ground on an ungrounded system must develop phase-to-phase fault for relay operation with the ood of greater damage to equipment.

unded System

main and about the only contended advantage for rounded system is that a grounded circuit can in service until it is convenient to shut down the -providing another ground does not occur on r phase. The main disadvantages are the diffi- nd cost of locating grounds.

e the main reason in favor of an ungrounded centers around the continuity of service, this be examined closely. Service continuity is so nportant to some industries that they will accept nce of tripouts due to multiple grounds or dam- outage due to transient overvoltage in the of service continuity until a shutdown can be d. The time and expense for locating grounds is e; it is a real problem, as indicated in Fig. 2. the way the argument runs. However, there are w industries in that category. Most plants can e a short shutdown; and there are always non- al services which can be temporarily de-energized ir a faulted circuit.

ost plants it is the *total down time* that is im- ; and since ground faults are quickly located on nded system through automatic and selective

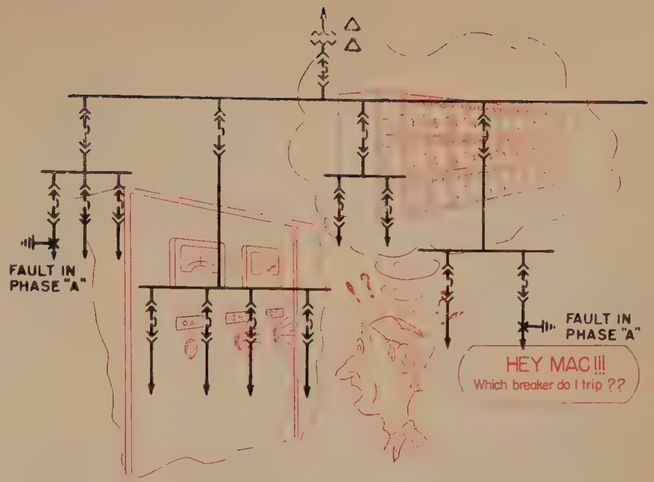
FAULT IN PHASE "A"
FAULT IN PHASE "A"
HEY MAC!!!
Which breaker do I trip ??

Fig. 2. Locating ground faults may be troublesome on ungrounded systems

overcurrent protection, the down time is usually less than for an ungrounded system. This has been the experience in plants which have changed to a grounded system.

Typical Experiences

The following cases illustrate the troubles associated with ungrounded systems. The few cases selected are typical and representative.

(1). A steel processing plant had many multiple failures (similar to that illustrated in Fig. 1) of motors and potheads on their ungrounded 2400-volt distribution system. After the system was grounded there were no more multiple failures and the over-all outage rate decreased.

(2). An inspector stated his experience(1) as indicating that, unless maintained in good condition, an ungrounded three-phase system of either 220 volts or 440 volts presents both fire and injury hazards when an accidental ground occurs on one phase.

(3). A workman ran an air hammer into a 2400-volt cable, causing a ground fault on the ungrounded system. Simultaneously a 250-hp motor on another feeder went to ground because of either transient overvoltage or a previous fault in the motor. The resulting short circuit (line-to-line) damaged the windings and the core laminations.

(4). The chief engineer of one large manufacturer, operating several plants with grounded and ungrounded 480-volt systems, said this: "We have lost a terrific amount of time and wasted man power chasing ground faults in ungrounded systems. I am ashamed to disclose the figure. I will never build another 480-volt ungrounded power system."

(5). A pumping station with an ungrounded 4600-volt system has had several cases of multiple motor failures. The operating records showed that out of 35 consecutive system faults, only two could be located, after ground detector indication, before a forced outage due to overcurrent relay operation (similar to that shown in Fig. 2).

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(1) *Electrical Construction and Maintenance*, vol. 50, no. 3, March, 1951, p. 122.

Many Grounding Arrangements to Select

There are many arrangements for grounding a power system. Most of them have a good engineering basis and have been used. A particular selection is complicated by economic rather than engineering considerations because the relative merits cannot be defined in terms of dollars and cents. That is the reason grounding methods have not been uniformly applied even within a given voltage class.

The few arrangements suggested in the following section for industrial plants are economical and consistent with good engineering practice and are the methods generally used.

One method of grounding that should bear serious investigation for industrial systems is the so-called corner-of-delta grounding. While this method offers the operating benefits of a grounded system it has one serious drawback and that is the absolute necessity of phase identification throughout the plant for proper protection of motors and feeder circuits; the motor over-load or circuit over-current relays *must* always be in the two ungrounded phases. Also, the voltage stresses are not equally divided, as they are with neutral grounding, because two of the phases are above ground by line-to-line potential. Therefore it is suggested that new systems use wye-connected transformers and ground the netural point; in existing delta-connected systems use a grounding transformer to establish a neutral point.

The scheme of mid-tap grounding of one winding of a 3-phase delta-connected transformer is used almost exclusively on 240-volt systems to obtain a 120-volt source. Because the mid tap is grounded rather than one of the phases, as in the corner-of-delta method, motor overload relays can be in any of the two phases and still protect the motor. Even so, the engineer should investigate the merits of a 208/120-volt system before adopting the mid-tap method.

HOW TO GROUND

Briefly, industrial practice is to limit the ground-fault current to a value consistent with proper circuit over-current protection requirements and yet minimize the damage to motors and generators, cable, switchgear, and any other metallic parts of the ground path.

On main power-distribution systems—for example, of 2.4 to 13.8 kv—a resistor is generally used to limit the ground current; the ground current usually ranges from 500 to 1500 amp and a good rule of thumb is to select the resistor for a current rating equal to that of the largest current transformer. On these systems, induction-type relays are used for ground overcurrent protection; and since the ground current is independent of the circuit load current—no current flows unless there is a ground—the relay can be set for a low pickup and fast operation.

The practice on low-voltage systems (that is, below 600 volts) is quite different and these are "solidly" grounded. There are two good reasons for this difference. First, even a small impedance in the return will limit the fault current; for example, with onl ohm in a 480-volt circuit (277 volts line-to-neutral) maximum ground current will be 2770 amp. The reason is that a different type of overcurrent prote device is used. While relays are used on high-vol systems they are rarely used for low-voltage. Here main feeder switching device is an air circuit bre which has self-contained and, practically speaking, adjustable overcurrent trip coils. These coils are in

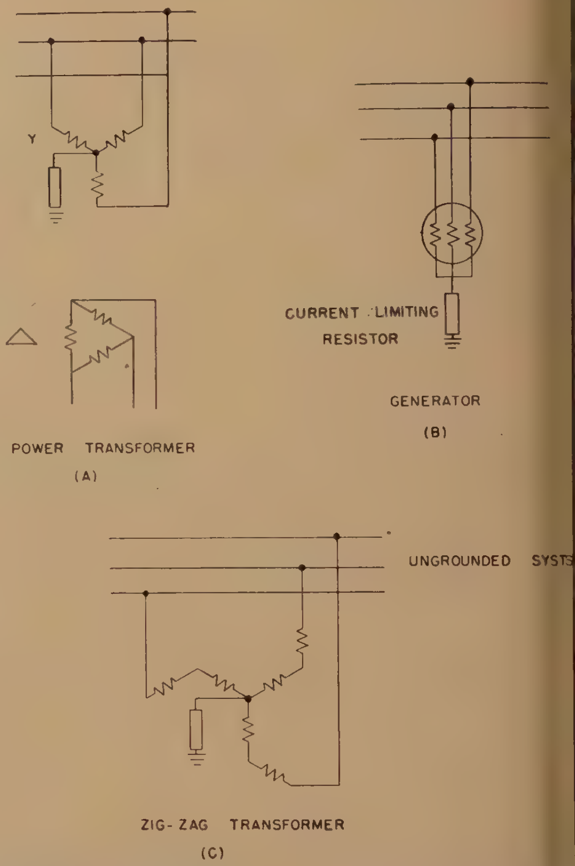

Fig. 3. Methods of establishing ground sources for wye-connected equi and for an ungrounded delta-connected power supply

phase lead; obviously they must have a trip set above the load current of the circuit. The breaker ings commonly used range from 225 to 1600 amp. Bra circuits have a lower current rating, and their tective devices are selected accordingly. Therefore a given fault current, the branch circuit protec device should operate before its main-feeder breake is this automatic selectivity obtained in actual prac that makes it so easy to locate grounds in a groun system—starting at the circuit that tripped.

Sometimes a reactor is used instead of a resistc limit the current. If the required level of ground cur is high the reactor is more economical. One applica is for generator grounding to reduce the ground-f current to the 3-phase fault value which is the maxin current for which generator windings are braced generator should not be solidly grounded unless coils are specially braced.) The level of fault curren reactance grounding must be higher than that requ esistance grounding to prevent transient over-ges.

eview of grounding practices for utility systems how some differences from those set forth here, a even seemingly contradictory. These are due y to the differences in operating requirements. xample, utilities have extensive overhead 2400-160-volt circuits exposed to lightning. These serve ipally consumer lighting loads from step-down formers and have very little direct-connected r load. These factors favor solid grounding. In ast, industrial plants have few if any overhead bution systems, but have a large percentage of t-connected motors; both of these factors favor ing the magnitude of ground-fault current. This is one example to show why some of the practices are ent although basically the objectives are the same.

. 3 shows the basic grounding systems; parts (A) B) apply when the neutral point of a transformer nerator is available. When that is not available the lled zig-zag grounding transformer (C) is used to e a neutral point. This transformer has a high dance to normal 3-phase load but a very low im-nce on a ground fault and therefore allows ground nts to flow. The current is divided into three equal onents in phase with each other and flowing e three windings. These transformers, in common with other grounding devices, are usually rated for 10-second operation.

A summary of grounding practices is given in Table I.

Ground at Power Sources Only

The system should be grounded at the power sources only, such as main incoming power transformers or generators. That may mean at each or several power sources; but in any case so that the system is always grounded. Likewise, each major bus section should be grounded.

The primary of step-down utilization transformers or the neutral point of motors should not be grounded, because multiple ground points increase the magnitude of the ground current and complicate the system relaying.

The 4160-volt system has caused most confusion on this point. The fact that 4160 happens to be 1.73 (wye) of 2400 does not mean that load-center transformers for 4160-volt systems must be wye-connected or even grounded. As a matter of fact, the standard primary winding for this voltage class is delta. No doubt the confusion on this point is a carry-over from utility practice in which 2400-volt single-phase transformers were reconnected from delta to wye to reduce the feeder voltage drop.

TABLE I: WHEN AND HOW TO GROUND INDUSTRIAL POWER SYSTEMS

nal System Voltage	Suggested Grounding Practice	Systems Having Wye-connected		Systems Having Delta-connected	
		Generators	Transformers*	Generators	Transformers
-VOLTAGE SYSTEMS, 600 VOLTS AND LESS					
/120 le-phase	Always operate grounded #	—	Solidly ground transformers mid-tap	—	—
/120 ase	Always operate grounded #	Use reactor**	Solidly ground transformer neutral	—	—
3-phase	Operated grounded. If system is in planning stage, prefer changing to 208Y or 480Y	Use reactor**	Solidly ground transformer neutral	Use grounding transformer. Alternately operate ungrounded	
or 600 ase	Operate grounded	Use reactor**	Solidly ground transformer neutral	Use grounding transformer.	
EE-PHASE HIGH-VOLTAGE SYSTEMS, 2400 TO 13,800 VOLTS					
)	Operate grounded	Use resistor	Use resistor	Use a grounding transformer plus resistor	
)	Operate grounded	Use resistor	Use resistor	Use a grounding transformer plus resistor	
)	Operate grounded. If system is in planning stage prefer changing to 4160Y	Use resistor	Use resistor	Use a grounding transformer plus resistor	
)	Operate grounded	Use resistor	Use resistor	Use a grounding transformer plus resistor	
00	Operate grounded	Use resistor	Use resistor	Use a grounding transformer plus resistor	

ese transformers are the source transformers for the particular voltage class.
quirement of the National Electrical Code.
is possible to obtain some generators with special coil bracing to withstand direct phase-to-ground faults; those generators can be solidly grounded.

Load-center Transformer Should Be Delta-wye

The primary winding of load-center transformers should be connected delta and that is now the industry standard. The secondary should be connected in wye to conveniently and inexpensively obtain a neutral point for grounding. The wye connection is a universal one, because the system thus can be grounded or ungrounded; the fact that the winding is wye does not mean the system must be grounded, although that is recommended. One large transformer manufacturer has standardized the wye connection.

In addition to the advantages of grounded-system operation, there is another advantage with the 480/277-volt wye-connected secondary: that is that 265-volt fluorescent lights connected line-to-neutral can be used. This lighting system is more economical than any other arrangement available to date (saving for a medium and a large factory layout being approximately $20 per kva of lighting load because of elimination of one transformation and the simpler wiring and switching systems). Also, there is the substantial saving in copper and steel, a factor which is becoming more important with the restrictions imposed by stepped-up defense effort.

Equipment Grounding System

It is extremely important to properly engineer and install an adequate station- and equipment-grounding system. Only when sufficient attention is given to the over-all requirements is there assurance of safety to personnel.

The main purpose of equipment grounding is safety to personnel by preventing a hazardous potential above absolute earth or ground on electrical equipment. Such a system should have a direct path to ground (for example, via the ground bus) to avoid the unintentional transfer of ground currents to various metallic parts of the building, equipment, piping system, etc.

For purpose of this presentation, the following definitions apply:

Ground bus is a metallic network used to connect a number of grounding conductors to one or more grounding electrodes. This is used in a broad sense to include the metallic network of the equipment grounding system.

Grounding conductor is a conductor used to connect an equipment, device, or wiring system with the grounding bus.

Grounding electrode is a conductor embedded in earth, used for maintaining ground potential on conductors connected to it and for dissipating into the earth current conducted to it. Generally, this consists of driven rods or the water piping system.

Example

The purpose of this example is to indicate the important elements that should be considered in establishing the equipment grounding system.

Assume a plant with an outdoor station stepp
down the incoming voltage to 13.8 kv for plant distri
tion. Further assume that the main 13.8-kv switchg
is located indoors, that conduit and cable circuits
used to distribute the power to the load-center
substations, and that the low-voltage distribution is
cable and plug-in busway.

The outdoor station bus should consist of a gro
"mat" composed of stranded copper conductors, cr
crossed and electrically interconnected, installed be
the surface. At points within and around this a
there should be driven rods of sufficient length
spacing to obtain a low ground resistance; one ohm
less is a good ground. To this ground mat should
metallic connections from the steel columns, tra
former tanks, switch handles, breaker frames, lightn
arresters, station fence, and all other metallic parts.

The ground bus between the outdoor station
the 13.8-kv switchgear will depend upon the type
power circuit. If lead-covered cable is used, the ca
sheath can serve as part of the ground bus. Also
metallic conduit having threaded joints is used, t
can constitute part of the ground bus. Sometimes
separate ground conductor is installed from the stati
ground bus to the indoor switchgear. In any eve
these metallic channels must be connected to the ou
door station ground bus and to the grounding bus
the switchgear.

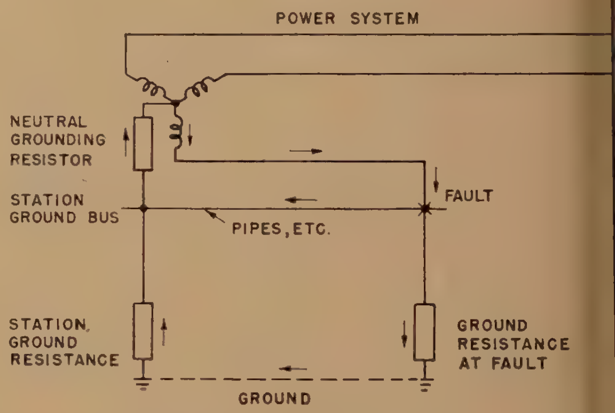
POWER SYSTEM
NEUTRAL GROUNDING RESISTOR
STATION GROUND BUS
PIPES, ETC.
FAULT
STATION GROUND RESISTANCE
GROUND RESISTANCE AT FAULT
GROUND

Fig. 4. Current paths during a ground fault. The resistance of the station
equipment grounding system should be low so that most of the curren
forced to return over that path

The cable circuits to the load-center transform
should also have a good continuous ground conn
tion. If the transformer secondary is wye-connect
its neutral should be connected to the low-volta
switchgear ground bus and also, if possible, to driv
ground rods near the transformer. The transform
tank should be connected to the same ground bus.

Within the building, the service piping systems shou
be bonded together and interconnected to the co
mon grounding bus. A ground bus should surround
building and should extend to interior parts whene
possible. Thus by interconnecting the piping, equ
ment ground buses, and structures with the main s

ounding bus a low-resistance grounding network
ble.

pment frames, such as of motors, should be con-
to the common grounding bus. Frequently where
notors are involved a separate ground bus is used
of convenience; but that too should be con-
to the main grounding system.

n plug-in busway is used, it is often convenient
ze its neutral bus as part of the grounding system.
op cable with a grounding conductor is available
a handy method for establishing part of the
ent grounding bus.

-down transformers for lighting should have each
or mid-point connected to the equipment
ing network.

ay not always be practical to go to the extent
d in the foregoing suggestions to establish a
ing bus; but, whatever is done, the maximum
ent exposed to personnel should always be in-
in the grounding network. Fatalities have oc-
due to improper equipment grounding.

l Bus Must Have Low Resistance

iously, the resistance of the station ground should
; but even more desirable and necessary in most
s low resistance of the equipment grounding
system. It is recommended that this be less than 0.1 ohm.

The reason lies in the relative resistances of the return paths. FIG. 4 shows that (assuming a properly designed grounding system) with a ground fault all or most of the current will return via the grounding bus rather than through the earth. Therefore, there will be little if any potential across the earth which constitutes the station ground resistance. Thus, the voltage of the ground-bus system, for example the frame of a motor, will be low and not hazardous to personnel. A low-resistance return path is especially important for low-voltage systems (that is, 600 volts and below) as the station ground resistance cannot be depended upon to be low enough to pass enough fault current to trip feeder breakers.

On higher-voltage systems where it is impractical to provide a metallic return path (for example, 4160- or 13,800-volt overhead feeders serving remote loads), the ground fault current must return via earth. That means that the station ground resistance should be low to reduce the shock hazard during faults.

Power systems for mining equipment, such as electric shovels, usually have a separate copper conductor for the return path and this is connected to the shovel frame and the station ground bus.

ITS AND SIDE LIGHTS

Joining Silicone Rubber to Steel

thod of joining silicone rubber to
d other surfaces in a permanent
ronger than the rubber itself, has
scovered. Key to the process is a
ne-like "primer," which forms a
bond between silicone rubber and
surfaces besides steel, including
ramics, aluminum, tin, and copper.

opment of the primer increases
ulness of silicone rubber in struc-
mbination with metals. Typical
ions would include engine and
nounts. Engines mounted on sili-
bber would produce greatly re-
vibration; delicate aircraft in-
ts similarly mounted would be
less subject to damage by severe wind-buffeting of aircraft or shock in landing. Heavy-duty washers or gaskets made of tough glass fiber bonded between layers of silicone rubber may also find industrial application.

To produce the bond, the liquid primer is brushed or sprayed on the metal or glass surface that is to be joined to silicone rubber. After drying, the surfaces are placed together under light pressure at a temperature of 250. The resulting bond withstands temperatures from −85 to +500 F. In laboratory experiments, the bond has shown a strength of about 700 lb per sq in. of holding area.

Testing Yarn Within Millionths of an Inch

lma may have had a deft finger
een eye at her spinning wheel, but
ld probably have trouble today
ng with modern electric devices
stablish the thickness of machine-
yarns within millionths of an

ently developed tester determines
ckness at the rate of 12 yards a
The equipment contains a photo-
recorder and other devices spe-
eveloped to make a permanent
f the thickness of yarns.

the aid of this new testing device,
ns in yarn can be detected on the
en the photoelectric recorder in-
dicates that the strands are running either too heavy or too light, thereby exceeding the satisfactory tolerances. According to textile experts, the instrument can be used to make quality tests on strands of every known fiber—cotton, woolen, rayon, or blends.

Prior to the introduction of this type of test, textile manufacturing had to be carried through to completion of the cloth before checks could be made for thickness variations. The new method provides a means of checking thicknesses at each successive stage in the manufacturing operation and eliminates many of the imperfections which were formerly present.

Keeping Trolleys on Schedule

A unique electric monitoring system enables one man to know the whereabouts of every streetcar and trolley coach along 600 miles of track and road serviced in Philadelphia. Using the monitoring equipment, a single dispatcher at headquarters can help to keep the hundreds of electric vehicles on time.

Nucleus of the system is a battery of 130 remote-control time switches and a two-way radio control. Complaints about delays in service have been reduced by more than 50 percent since the system was installed. Approximately 200 delays are handled daily through the monitoring network.

Aided by the remote-control time switches, the dispatcher can determine the headways between streetcars or trolley coaches at recorder locations along the lines. When normal distances are not kept between vehicles, warning lights and a bell signal a warning to him. Thus alerted by electric devices, he can notify one of a force of 42 mobile troubleshooters via radio to investigate and clear up the delay. Prior to this, delays could not be detected at once. Telephone reports had to be made to field offices before an investigator could be dispatched to the trouble spot.

The system is extremely flexible and can be changed, simply by turning a knob, to work effectively during peak load as well as slack periods.

VACUUM-DRYING OF ELECTRICAL INSULATION IN THE SERVICE SHOP

Simplified, high-quality technique duplicating as nearly as possible the process and equipment used by the manufacturer

By N. R. MALEADY

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General Electric Company

Noel R Male

THE presence of excessive amounts of absorbed moisture in electrical insulation represents one of the dangers to long life of electrical equipment. The problem of drying is one of considerable importance, not only to the manufacturer of electrical equipment but to the user as well.

While straight oven drying once provided a satisfactory method for the average service shop, present-day operating requirements have indicated the desirability of vacuum drying. In the field of transformers, for example, the unit insulation is now being subjected to higher electrical stresses than ever before, and therefore requires more thorough drying. Vacuum is also playing a more important role in dielectric impregnation, since higher impulse strength can be achieved, in many cases, only by using vacuum for the complete removal of air before impregnation.

Recently many electrical utility companies have expressed a desire to expand their present service-shop facilities to provide them with the latest in vacuum-drying equipment. They wish to duplicate as nearly as possible the higher-quality process and equipment control used by the manufacturer. This article represents a generalization of General Electric specifications for a somewhat simplified high-quality vacuum-drying technique.

Moisture in Insulation

The exact role that moisture plays in the performance and life of electrical insulation is not easily defined. It is generally agreed, however, that large quantities of moisture in sealed apparatus is highly undesirable. The presence of moisture in electrical apparatus may reduce its dielectric strength as much as 50 to 75 percent. It has been pointed out in the literature that a definite moisture equilibrium exists in sealed apparatus between the insulation, the dielectric fluid, and the air space.(1) In general, on this basis, it can be concluded that in sealed apparatus a moisture content in excess of a few percent may result in condensation of moisture within the equipment, assuming the normal temperature changes expected in operation.

When either impregnated or unimpregnated moisture-free cellulose insulation must be exposed at room humidities for any reasonable length of time for repair, there is serious danger of appreciable moisture pickup which will necessitate redrying. While neither the varnish or oil film seriously impedes reabsorption of
ture by dry insulation, they do provide a reaso
margin of safety to permit normal handling, since
reduce the rate of reabsorption to the order of $\frac{1}{3}$
that of dry untreated insulation.

Rapid Drying of Insulation

The general theory of drying is relatively si
The insulation temperature must be raised to a re
ably high value in order to increase the vapor pre
of the absorbed moisture and increase its rate of
sion through the insulation. The highest tempera
acceptable for various types of electrical insulatio
pends upon the particular materials of construc
However, a temperature of 100 C will generally pe
reasonably rapid drying without deteriorating a
the insulating components. The change in temp
ture, in addition to increasing the rate of mois
diffusion, also automatically lowers the relative
midity of the surrounding air. For example, hea
room air of 50 percent relative humidity to 10
results in a relative humidity of about one perc
According to the data of McLean(2) this would r
in an equilibrium moisture content in the insulatic
slightly higher than 0.4 percent water by weight.

The primary consideration in rapid drying i
raise the temperature of the work as quickly as
sible. Good air circulation at a velocity of 200 ft
minute or better can contribute as much as 50 per
decrease in the heating-up time, or approximatel
percent in total drying time, of typical electrica
sulation over natural convection or radiation.

Where time is not critical, however, the additi
cost of recirculation may not be economically justi
It should be noted that poor air circulation is ent
worthless, since simple sidewall heat provides mod
thermal circulation. Where a recirculating syste
used, room air is adequate. With approximatel
percent air being spilled in circulation, the rela
humidity is kept sufficiently low that it offers no
pediment in drying.

The most effective way to lower the relative hum
of a space, however, is accomplished by the u
vacuum. With a system running at 29 in. of vac
the in-leakage of room air of high humidity has
gible effect on the relative humidity of the d
chamber. For instance, in a system maintained

cuum the in-leakage of relative-humidity room ercent RH) will create a condition of less than ent relative humidity at 100 C, which may be ed bone dry for all practical purposes.

n together, the effect of heating to increase the ressure of the water and the use of vacuum to he surrounding relative humidity effectively lrying.

ning Drying End Point

stimation of the end point of drying is one of e serious problems encountered in the drying ing of electrical insulation. The actual measure- the total moisture evolved in the given sys- mpared to the original moisture content of the n, could give a reasonably close approximation d point of drying. However, in most cases the can serve only as a guide, since accurate ments are difficult or impossible.

easurement of moisture removed in the vacuum hrough condensation in a water-cooled con- only very rough, since the rate of water re- ust be quite high to permit condensation of the apor at such temperatures. For example, a vacuum system having a 300-cfm vacuum ith a 1-cfm leak would require in excess of ds per-hour rate of evolution of moisture be- condensation would appear in the water- ondenser operated at 60 F (15 C).

nsulation-resistance method of electrical meas- has not been entirely successful in indicating val of moisture from electrical insulation, and has been superseded by that involving the measurement of insulation power factor. Measurements may be taken between high and low windings or from one or both windings to ground. The exact values obtained during the drying process are not of importance; the trend, however, gives a good clue to the drying rate. Since insulation power factor rises with temperature, the measurements mean very little until the work has reached a constant temperature. At that time the power factor should decline as moisture is removed until a constant value is reached, indicating no further drying.

One nonelectrical method which may be used satisfactorily in conjunction with the power-factor method requires a particular knowledge of the vacuum system being used for drying. Provided the system has a constant leak rate from run to run, it should give a constant blank-off vacuum (that is, maximum vacuum attainable) at equilibrium. As long as moisture is being evolved from the cellulose insulation the blank-off value cannot be achieved; however, when all or nearly all the moisture has been removed the system should return to its lowest value.

The Drying Cycle

In the field or service shop where the combination system of hot-air circulation and side-wall heat would be used, a typical cycle for drying a moderate-size transformer would operate as follows:

> The unit is connected for measurement of power factor and temperature. The high-voltage leads are tied together and taken from the tank as one power-

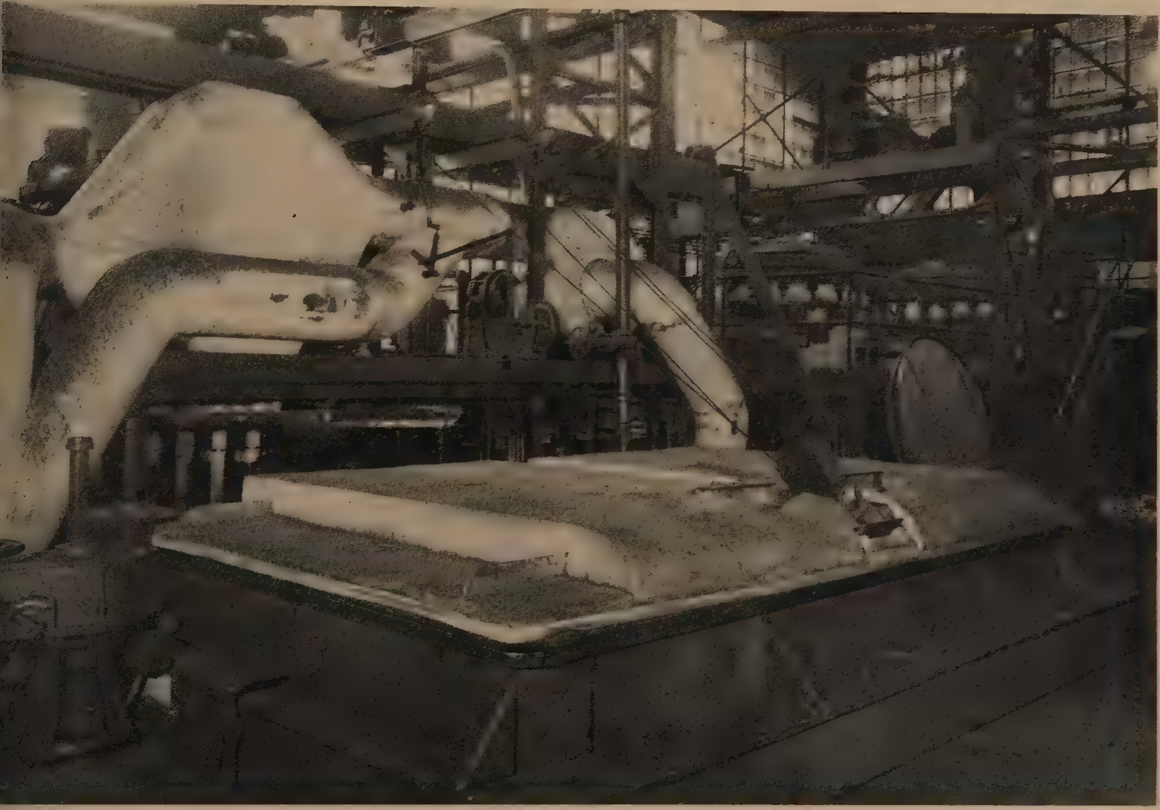

Fig. 1. Typical vacuum-drying system set up for use

factor lead; the low-voltage leads are grounded, and ground forms a second lead to the power-factor bridge. The unit is then connected to approximately four thermocouples, each of which is buried well into the transformer insulation. Temperature control is set at 105 C, to regulate the temperature of the circulating air from the external heat exchanger as well as the temperature within the tank.

During the heating process, air is circulated until the temperature of the hottest point within the transformer reaches approximately 70 C. The circulating system is then turned off and vacuum applied for one hour with the use of side-wall heat. Recirculating air is then turned on until the temperature has risen to 80 C, at which point the vacuum cycle is repeated. This procedure is repeated for every 10 C rise, until all temperatures are at 100–105 C. Full vacuum is then applied and the side-wall heat controlled at 105 C.

The process of moisture removal may be speeded up at this stage by periodically breaking the vacuum by 50 mm every hour, using relatively dry air. If power-factor measurements are being taken, these should be checked every four hours during the final vacuum period. When the power factor has remained constant (at constant temperature) for eight hours, the units may be considered dry. The vacuum in the system at this stage should have reached its lowest value.

A typical system for this form of vacuum drying in the service shop or in the field is shown in FIG. 1. While it does not have the complexity of a modern factory drying installation, it does provide satisfactory performance, with good control, at minimum expense. It would consist briefly of the following:

Vacuum Tank

The vacuum tank will measure 10 ft by 10 ft by 12 ft high. If circulating hot air is used, the tank should be provided with plenum chambers across opposite sides of the tank to provide uniform circulation. Each chamber should be in the order of 10 in. deep and provided with 1-in. holes on 12-in. centers in order to impart some jet velocity to the circulated air. These plenum chambers may be connected to the external heat exchanger and blower system through vacuum-tight valves.

If it is advisable to set the tank in a pit, it should extend approximately 35 in. above the floor level to provide a safe working height. The tank cover need not be bolted, since a good gasket surface together with the external air pressure should give a satisfactory seal. The gasket must be both oil- and heat-resistant. It is generally purchased in suitable lengths to make one piece, leaving only one scarf joint to be sealed or vulcanized.

In the construction of the cover it is wise to support the back edge by the use of an eccentric cam which will permit raising of the cover from the gasket before opening. This will eliminate excessive gasket wear on the rear edge.

The tank should be provided with auxiliary side- heat of approximately 13,333 Btu/hr (20 kw) of sq ft of steam-coil surface (where used with 10 steam). Where electric heat is used it is advisab use units of low current density. They shoul mounted on the outside of the tank, provided wi small dead-air space, and covered with two inch insulation not in contact with the heaters.

Auxiliary Equipment

The air-circulating system would consist of a c lating blower of approximately 20,000-cfm capacit a static pressure of three to four inches. This sh be provided with an external heat exchanger of app mately 20,000 Btu/hr (30 kw). A good rotary vac pump of approximately 100-cfm capacity shoul adequate; this will provide a vacuum of better 29 in. Care should be taken that the pump h reasonably large oil separator, to permit han quantities of water. As a protection against overl ing the vacuum pump and impairing its efficienc water-cooled condenser of 50 sq ft should be Compressed air, suitably trapped, may be used source of dry air for periodically breaking the vac

The instrumentation should include a thermoco type recorder-controller having a range of 0 to 20 to be used for control of the heat to the tank and exchanger. A thermocouple-type multipoint rec should be used for measuring internal temperat A 110-volt capacitance bridge should be provide power-factor measurements.

In drying moderate-sized power transformers possible, using such a scheme, to produce elect insulation with a moisture content well under percent moisture (by weight of insulation) withi to 100 hours. The actual heating time required to the bulk of the equipment up to temperature (10 largely determines the length of the total drying c Where the circulating hot air is most effective (a the case of a transformer directly in front of the of hot air) even shorter drying cycles may be reali

The final flooding of the dried transformer wit dielectric liquid within the vacuum tank will ther duce its tendency to reabsorb moisture during tanking operation and insure a finished product of quality. It is recommended that the manufacture the apparatus being dried be consulted to ascertain precautions or special measures which should be ta in vacuum-drying a particular piece of apparatus, certain transformers, for example, cannot stand vacuum. While the equipment described here ca used for such apparatus, certain changes in proce may be required.

References

(1)"Moisture Equilibrium Between Gas Space and Fibrous terials in Enclosed Electrical Equipment," by J. D. Piper; *Transactions*, vol. 65, December 1946, pp. 791-797.

(2)"Absorption of Water by Papers at Elevated Temperatu by C. C. Houtz and D. A. McLean, Bell Telephone Monog B1135, 1938.

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This is one of six I-R high-pressure boiler-feed pumps at the Windsor Station. The others are giving fine performance also. Four of these were installed in 1941. Here are their records*:

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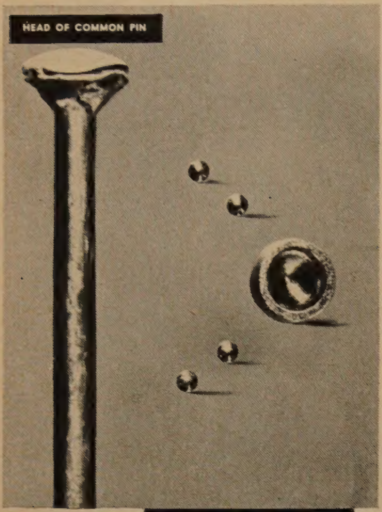
NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

Miniature Ball Bearing



TINY NEW MINIATURE BALL BEARING SHOWN NEXT TO COMMON PIN

A miniature pivot ball bearing having an outside diameter of 1.5 millimeters. Diameter tolerance is held to plus zero and minus two ten-thousandths of an inch. To achieve these tolerances, measurements are made with instruments accurate to 20 millionths of an inch. The pivot shaft holds the balls in place. The raceway wall itself is so designed that its mass occurs at points of greatest strain. This permits relatively heavy loads under severe conditions of shock and vibration. Shown in the illustration is a highly magnified portion of a common pin. Next to it is one of these smallest of pivot ball bearings, showing the tiny balls.—*Miniature Precision Bearings, Inc., Keene, New Hampshire*

Oscilloscope

A five-inch oscilloscope, Type ST-2C, designed for use in microwave installations. The vertical sensitivity a-c input is 0.075 volts rms per inch; the vertical amplifier frequency response, prove and a-c, is 20 cycles to 3 megacycles, +0, −30 percent. Adequate drive from the horizontal amplifier is available to expand the trace to several times the diameter of the cathode-ray tube. This permits a good display of short-duration pulses and allows closer observation of portions of a wave pattern. Wide frequency response is obtained without recourse to peaked-amplifier coupling circuits, resulting in excellent transient response. D-c operating potentials from an electronically regulated power supply allows the oscilloscope to be used under unusually severe power-line fluctuations.—*Commercial Equipment Division, General Electric Company, Electronics Park, Syracuse, New York*

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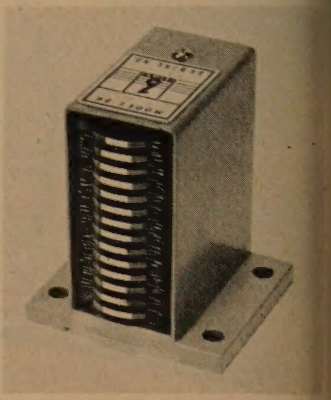

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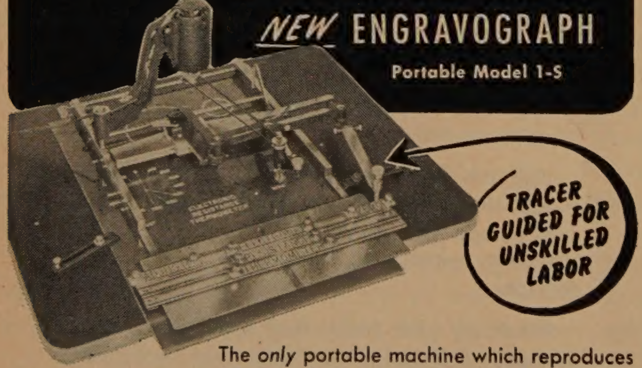

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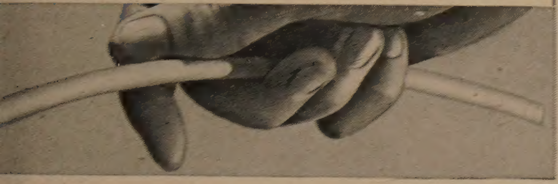

with band widths up to 2 megacycles can be delayed 25 to 10 microseconds. Available in lengths up to 100 ft. quals approximately ½ microsecond per foot. Charac- impedances of 1100 and 400 ohms per foot are avail- y ordering in bulk, lengths can be cut to fit specific Can be bent into 4-inch diameter coils. Uses include n and development of special circuits for electronic See Bulletin GEC-459 for further information.

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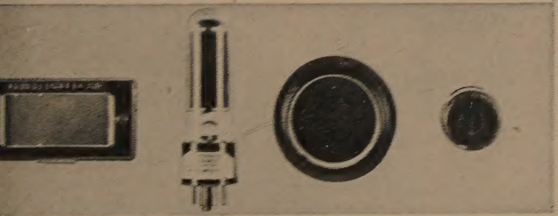

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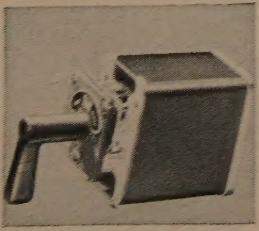

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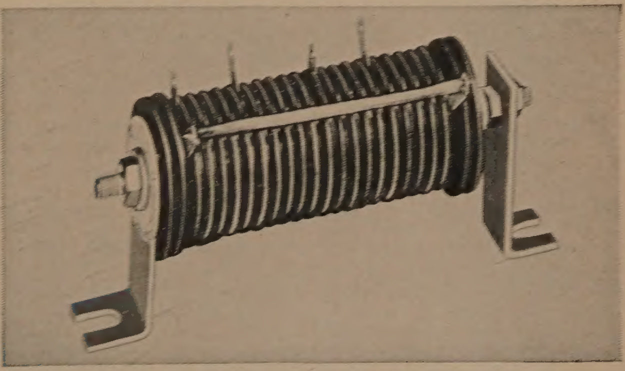

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BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery: none sent on approval.)

CHEMICAL THERMODYNAMICS

Frederick D. Rossini—John Wiley & Sons, New York. 1950. 514 pp. $6.00.

According to the author, this book is intended for those having some background in physical chemistry and calculus. The topics have been introduced in a logical manner and the emphasis is on the application of the laws of thermodynamics as applied to actual chemical problems. The symbolism used is that of Lewis and Randall.

The first five chapters cover background material such as definitions of terms, units, and basic constants. The large middle section gives a substantially complete account of modern chemical thermodynamics, and the concluding five chapters give a number of examples of the application of the principles developed to special chemical problems. The reviewer would have liked to see many more of these examples interspersed throughout the text. The author, however, adds a number of good problems after each chapter to test the students' grasp of the principles treated.

The book is highly recommended as a modern authoritative text on the subject.

A. L. MARSHALL

INDUSTRIAL AND SAFETY PROBLEMS OF NUCLEAR TECHNOLOGY

Edited by Morris H. Shamos and Sidney G. Roth—Harper & Bros., New York. 1950. xiii+368 pp. $4.00.

Here are assembled the papers presented at a 1950 conference on the title subject. The presentation is definitely not for experienced nucleonic scientists but is reasonably nontechnical and addressed to laymen and governmental and business personnel interested in ordinary health and accident precautions.

Over half the text sets the stage for understanding the rapid growth in general use of radioactive materials and the extrapolation of ordinary measures of safety and good housekeeping to provide adequate precautions for working with differing amounts of radioactivity. Several of the quoted figures for "tolerance levels" are now obsolete.

The rest of the book deals with such problems as health monitoring, methods of measurement, control of gaseous, liquid, and solid wastes, fire fighting, and employee insurance.

This book should be extremely useful to educational, industrial, and medical groups initiating experimentation with small quantities of radioactive isotopes. It should also be useful to public health, safety, and insurance groups as the use of radioactive materials becomes increasingly more widespread throughout the country. Literature references are adequate for those who wish to pursue the subject further.

H. H. RACE

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Russell M. Kerchner and George F. Corcoran—John Wiley & Sons, New York. 1951. 598 pp. $5.50

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Norbert Wiener—Dover Publications, New York. 1951. 201 pp. $3.95.

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SPACE—TIME—MATTER (1st American printing of 4th Ed.)
Hermann Weyl (translated by Henry L. Brose)—Dover Publications, New York. 1951 (1922). xiv & 330 pp. $3.95

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